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GRAVEL CULTURE

For

GROWING ORNAMENTAL GREENHOUSE CROPS

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GROWING ORNAMENTAL GREENHOUSE CROPS IN GRAVEL CULTURE

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INTRODUCTION

"Gravel culture" is a general term which applies to the growing of plants without soil in an inert medium into which nutrient solutions are usually pumped automatically at regular intervals. Haydite (shale and clay fused at high temperatures), soft- or hard-coal cinders, limestone chips, calcareous gravel, silica gravel, trap rock, crushed granite, and other inert and slowly decomposing materials are included in the term "gravel."

As a laboratory technique, growing plants without soil in nutrient solutions dates back to the middle of the nineteenth century, to the original work of Bousingault, Liebig, Salm-Horstmar, and Sachs, who provided the mineral nutrient theory of today. Their techniques were elaborated and improved by such workers as Knop, Tollers, Pfeiffer, Tottingham, Shive, Hoagland, and others.

The first practical application of growing plants without soil was made by Pember and Adams (13), who attempted to grow carnations in sand to determine their nutritional needs. Biekart and Connors (2) in 1927 succeeded in developing a satisfactory method of growing carnations in sand which was surface-flushed regularly with nutrient solutions. Laurie (9, 10) and his assistants were likewise engaged about the same time in growing different flowering crops in sand with additions of nutrients in dry form. Gericke (6) was one of the first to advocate the commercial use of water culture, the growing of plants with their roots constantly immersed in a nutrient solution.

Automatic subirrigation received its impetus from the work of Eaton (5), who demonstrated that solutions supplied automatically to sand from below saved much labor and were quite satisfactory. Withrow and Biebel (17) developed the original mechanics in 1936, and a little later a somewhat similar arrangement was introduced by Connors and Tiedjens (3). In 1937, workers at the Ohio Agricultural Experiment Station (11) began using the same method, following the mechanical setup of Withrow and Biebel. In place of sand, coarse aggregates were used.

The reasons for the attempts to apply such methods to the practical culture of crops in the greenhouse are several. Since soil is a complex medium, absolute control of nutrition is difficult, and even the most expert growers have crop failures frequently. The automatic subirrigation method with solutions supplied to plants growing in an inert medium provides an exact and uniform system of procedure with ease of modification to conform to environmental variations. The labor saved by such a procedure is likewise to be considered, as well as the continued use of the medium selected without the frequent changes necessary when soil is used. Further advantages lie in the greater uniformity of quality of the crops so produced and the possibility of higher production due to optimum growth conditions. It must be understood, however, that if perfection of growth is attained in soil, just as good quality and as high a production can be expected in soil as in soilless culture. Although it is possible to grow many ornamental crops successfully, those which indicate greatest economic return on the investment are roses, gardenias, carnations, sweet peas, chrysanthemums, and snapdragons.

The work that was started in 1937 at the Ohio Agricultural Experiment Station has gradually progressed, and a considerable area of the greenhouse space is now devoted to soilless culture. A large variety of crops has been grown successfully, and many of the initial difficulties have been overcome, so that it is now safe to make specific recommendations with the expectation of success, provided these are followed exactly. Many commercial establishments have likewise tested this procedure, at first on a small scale, later gradually enlarging to devote considerable space to the growing of crops commercially without soil.

Because many small plots were needed to secure the required experimental data for this work, inexpensive units were devised by several graduate assistants (Arnold Wagner, Joseph Fueglein, Raymond Hasek, and D. C. Kiplinger) of the Ohio Agricultural Experiment Station and located at Columbus.

SMALL EXPERIMENTAL PLOTS

In figure 1 is diagramed the assembly of a unit containing a number of small lots. AP is an air pump controlled by time clock TC. B is a bleeder made by placing a pinch clamp over a piece of 1/4-inch by 5/64-inch rubber tubing and almost closing the aperture. A bleeder at each end of the main air line will be sufficient to allow for escape of air following pumping so that the plots will drain quickly. The main air line consists of a pipe tapped and drilled at regular intervals to allow for the connection of 1/4-inch short nipples for air outlets. The area of the pipe for the main air line should be slightly greater than the sum of the areas of the air outlets. This size insures uniform air pressure to each of the plots. O stands for air outlets for carboys made of ¼-inch short nipples. The diagram illustrates how 40 plots can be operated simultaneously.

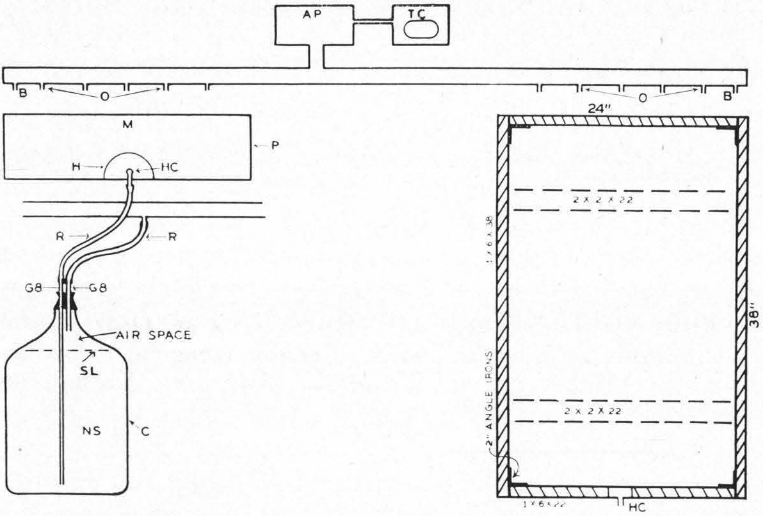

Fig. 1.—Diagram of a small plot assembly

P is the 2-foot by 3-foot by 6-inch experimental plot. H is the half-tile, M the medium to be used, and HC a male hose connection screwed into the front board. R is ¼-inch by 5/64-inch laboratory rubber tubing cut long enough to allow for complete removal of the rubber stopper and glass tubing from the carboy for additions of water and nutrients.

G8 is 8-millimeter glass tubing. The short piece does not extend into the solution, but the long piece extends to one-half inch from the bottom of the 5-gallon carboy C. A No. 6 two-holed rubber stopper must fit tightly enough in the neck of the carboy to prevent the escape of air. SL is the level of the nutrient solution NS maintained in the 5-gallon carboy. The solution level SL should be maintained at the point illustrated in figure 1, as some air space is necessary to keep the nutrient solution from backing up into the main air line; furthermore, the volume of solution in the carboy at this point is just sufficient to fill the 2-foot by 3-foot by 6-inch plot within 1 inch of the top. Pumping to this level prevents algae growth on the surface of the medium.

An inexpensive pump and motor manufactured for paint spraying are adaptable for use as a source of compressed air. When the motor is in operation, compressed air is pumped through the main air line, and a uniform pressure is built up in the air space above the solution level SL in each of the carboys. This pressure forces the nutrient solution into the long piece of G8 glass tubing leading to the plot P and thereby fills the plot. A time clock is a convenient device for regulating the period necessary for the air pump to empty completely the carboy C. Some pumps are so constructed that air will leak back through them and thus dissipate the pressure. No bleeders are necessary with such pumps, as the solution will drain back by gravity into the carboy.

As many as 40 small plots can be operated successfully with a paint sprayer motor and pump. It will take about 10 minutes for pumping and 20 minutes for complete drainage of 40 plots operated simultaneously.

When the area of the main air line is slightly larger than the sum of the areas of the air outlets, pumping will be uniform so that plots in various sections of experimental greenhouses can be used, as is often necessary under various light, temperature, and other environmental conditions.

The construction of plot small enough to be filled from a 5-gallon carboy is diagrammed in figure 1.

The bottom of the plot is constructed by placing two pieces of 1-inch by 12-inch by 38-inch lumber side by side and nailing them to the two pieces of 2-inch by 2-inch by 22-inch lumber indicated by the dotted lines. These 2-inch by 2-inch by 22-inch pieces prevent sagging of the bottom when the plot is filled with medium. The sides are then cut to fit on top of the bottom of the plots. At this time a hole should be drilled in the board that will be the front of the plot. The hole should be located flush with the bottom of the plot to allow for complete drainage of the plot after pumping. This hole is to accommodate the male hose coupling and should be slightly smaller than the diameter of the coupling to ensure a tight fit. The hose coupling should fit into a 1/4-inch or 3/8-inch hose to allow for ease of removal of the rubber tubing.

The sides are then nailed onto the plot bottom and to each other at the end. The 2-inch by 2-inch by 22-inch pieces should be underneath, not within the plot. Then the 2-inch angle braces should be screwed inside at each corner about 4 inches up from the bottom to prevent the boards from pulling apart when the plot is filled with medium. The plot is then waterproofed on the inside only with asphalt emulsion or any similar substance not toxic to plants. Sometimes it is difficult to waterproof the plots completely because of warped boards. Strips of laboratory cheesecloth are laid on top of the wet asphalt emulsion at all points and are thoroughly impregnated by the application of additional emulsion. Two coats are usually sufficient. When the cheesecloth is placed behind the angle irons before they are permanently screwed in place, a greater margin of safety that the corners will remain waterproofed is secured.

A container of similar dimensions constructed of reinforced concrete with provisions for drainage is more satisfactory than a wooden container. Leaks occur less frequently, and there is no danger that the sides will separate from each other or the bottom when the plot is filled with medium.

Fig. 2.—Numerous small plots can be operated successfully with an air compressor.

Before the assembled plots are filled with medium, the half-tile is placed on the bottom of the plot directly in line with the hose connection. An asphalted eaves trough may be substituted, but zinc toxicity is often encountered when the asphalt deteriorates. The purpose of the tile is to allow the solution to spread uniformly and quickly throughout all parts of the plot and to prevent the entrance of medium into the rubber tubing. The use of black iron window screen is advised at the joints and end of the tile. The tile should not fit perfectly on the bottom of the plot, because entrance and exit of the solution will be hindered. Pieces of wooden plant labels placed under the tile eliminate this difficulty.

After the equipment has been assembled, the plot is filled with medium and connected to the 5-gallon carboy. It is essential that the plots be tilted slightly toward the front to permit free drainage, as solution standing on the bottom of the plot seems to inhibit plant growth.

When all installations have been made correctly, the successful operation of many plots depends on the maintenance of the correct solution level in the carboys. The complete pumping of some plots while others are only partially pumped will result in a release of air pressure and immediate drainage of all plots.

BENCHES

Construction

A bench for growing crops in an inert medium must have perfect drainage. For greenhouse benches a V-bottom with a slope of 1½ inches from the side to the center of the bench is sufficient. No lengthwise slope to the bench is necessary if inlets and outlets are installed every 20 feet. Without these inlets and outlets, rapid drainage is impeded, and under such conditions a lengthwise slope of 1 inch to 100 feet is desirable on benches not over 100 feet long. On longer benches, difficulty with uniform moistening of the medium will be experienced because of the slope, and level benches with additional inlets and outlets must be constructed. The sides of the bench may be 6 to 8 inches high.

Materials

CONCRETE.—To date, concrete has been universally recommended as the ideal type of bench material for gravel culture, but it has serious disadvantages. Concrete develops small cracks with age which leak and require frequent attention to prevent undue loss of the nutrient solution. Settling of benches made of this heavy material causes water pockets in the bench which inhibits root action and reduces growth of the plants. The greatest fault with concrete is its inability to withstand steam sterilization, as the lack of sufficient reinforcing and the expansion and contraction of concrete develops large cracks which necessitate repair each time the bench is steamed. Considerable time is required for repair and difficulty is experienced in making the larger cracks completely watertight.

Concrete benches intended for gravel culture should be coated inside with a watery dressing of asphalt emulsion and then covered again with a thicker coating. As soon as dry, the benches should be filled with water and tested for leaks. If any develop, the bench should be cleaned adjacent to the cracks to remove loose flaky concrete or asphalt. The area should be flamed with a blowtorch to dry it thoroughly. A watery dressing of asphalt emulsion should be applied with a paint brush to penetrate all cracks and it should then be allowed to dry. Another coat of a watery asphalt dressing should be applied and while still wet, several thicknesses of cheesecloth or fiberglass should be laid over the entire area and painted with thinned asphalt emulsion. This should dry and again be painted with a thicker asphalt emulsion. After drying, still another application of thicker asphalt emulsion will insure against troubles from leaks. A cheap grade of emulsified asphalt, such as is used for road building, is satisfactory, provided it contains no oil or tar. One gallon of undiluted asphalt emulsion will cover about 50 square feet of surface.

If flat-bottomed concrete benches have already been built, they can be converted to gravel culture. The extra inlets and outlets should be installed before the new V-bottom is poured. Holes should be drilled in the center of the bench 20 feet apart, large enough to accommodate a 1 or 1¼ inch pipe. A 6-inch pipe nipple of the desired size threaded the entire length is best suited for this purpose. A lock nut should be screwed on one end of the nipple so the pipe is flush with the face of the lock nut. This is then placed in the bench so the lock nut is resting on the inside of the bench bottom with the bare end of the pipe extending below the bench. Another lock nut should be screwed on the nipple from the underside of the bench and turned on tightly so the nipple is firmly locked in place. Then a form should be made as shown in figure 3 to fit within the bench.

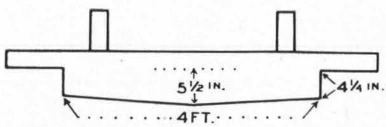

Fig. 3.—Form used to convert existing flat-bottomed concrete benches into a modified V bottom.

The inside of the bench should be covered with emulsified asphalt to prevent the old concrete from binding with the new, and if drainage holes are large, they should be covered with old cheese-cloth and asphalt. A dry concrete mix should be prepared from a one to four mixture of cement and AAA Haydite or sand. This mixture is placed in the bench and tamped roughly into the form of the modified V.

To finish the V in the bench, the form (fig. 3) should be pushed down into the wet concrete and moved back and forth. The concrete should be smoothed with a metal trowel. To minimize the amount of water in the bottom of the V, a short length of 1-inch pipe should be rolled back and forth in the V to form a notch or small depression. The water that will stand then will be in the depression under the tile, and no damage will result. A layer of concrete at least one-half inch thick should be retained between the bottom of the V notch in the V and the top surface of the old bench, to prevent cracking of the new concrete and to cover completely the lock nuts holding the pipe nipples in place.

STEEL.—Benches made of this material are expensive but will last indefinitely, provided the problem of corrosion can be overcome. Although asphalt dressing should be applied and while still wet, several thicknesses of asphalt emulsion is satisfactory for this purpose, a material known as Continental Waterproofer, made by the Continental Products Company, Euclid, Ohio, has proved highly effective in preventing corrosion. The entire bench should be covered with this material and allowed to dry before water is placed in the bench. The red lead paint which is universally used for corrosion prevention has not proved satisfactory under greenhouse conditions. Steel expands and contracts with the changes of temperature during steaming. It is one of the most promising successors to concrete for benches.

ALUMINUM.—At present the cost of fabrication of this material to the desired shape is too high to recommend installation of aluminum benches. They offer a perfect solution to the problems of a gravel culture bench as there is no corrosion under the conditions prevailing in gravel culture and steaming does not induce deterioration.

WOOD.—Benches made of wood cannot be used for gravel culture because of the difficulty of maintaining a watertight structure caused by age, sagging, and steam sterilization. All these tend to open the joints between the wooden members of the bench.

Tanks

In order to provide suitable containers for the nutrient solutions, tanks are installed under benches or in other suitable locations. Such tanks have several requisites. They must be waterproof, acid resistant, and of sufficient size to hold about 40 per cent of the total volume of the benches that they fill. These tanks can be made of concrete, wood, or metal. For small installations, milk vat or even grave vaults have been used. All tanks made of concrete should be coated with sodium silicate diluted one part to four of water, emulsified asphalt, or both. Wooden and metal tanks should be coated with asphalt and made absolutely acidproof. It has been suggested that tanks should contain enough solution to equal the total volume of the benches instead of the 40 per cent recommendation here.

Although true that a larger volume of solution makes it easier to maintain the proper levels of nutrients, the additional costs of construction are so high as to make such recommendations impractical. For benches over 100 feet long, tanks can be placed in the middle of the house.

Although individual tanks for benches are recommended on small installations, as many as 12 benches have been supplied from one tank in commercial practice with a single crop or variety. This arrangement is not advisable if several crops are being grown simultaneously, for then the advantage of solution manipulation is nullified.

Inlet Pipes

Black iron pipe, not galvanized, should be used for the inlets. For a 100-foot bench, one inlet of 1- or 1½-inch pipe near the pump at the end of the bench is sufficient, although better drainage can be provided by the placing of a separate pipe under the bench or alongside (fig. 4 and 5). The size will depend on the length of the bench. For small installations, 1½-inch pipe will suffice. Proportionally larger sizes are needed for long benches. Openings of 1-inch pipe spaced 20 feet apart in the bottom of the V in the bench are connected to the pipe line under the bench by rubber hose or other suitable material. Where several benches are so equipped, the pipe lines should connect to a central header whose area is slightly greater than the sum of the areas of the pipe lines leading from it. Uniform pumping of all benches will be obtained, for the pressure of the solution at all pipe openings in the header will be equal. All inlets to the bench should be flush with the bottom of the V and completely waterproofed, since they are frequently the sources of leaks.

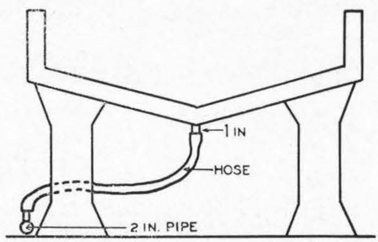

Fig. 4.—Pipe for extra inlets placed alongside the bench instead of underneath.

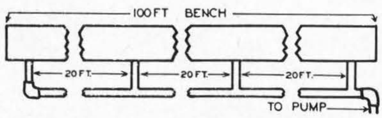

Fig. 5.—Lengthwise view of 100-foot bench with placement of extra inlets.

Automatic Siphon

Drainage of the nutrient solution back through the pump is often slow because of the presence of the pump impeller. An automatic siphon (fig. 6) facilitates rapid drainage from the bench, as most of the solution does not pass through the pump.

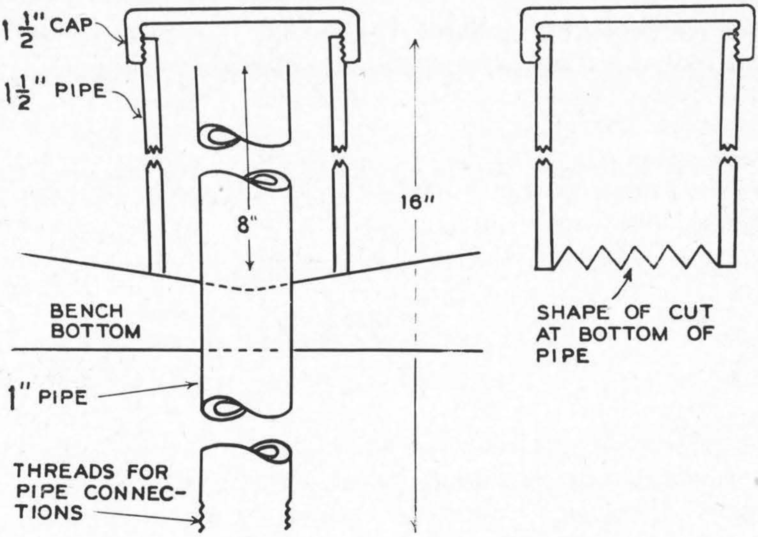

Fig. 6.—Automatic siphon for rapid drainage of benches

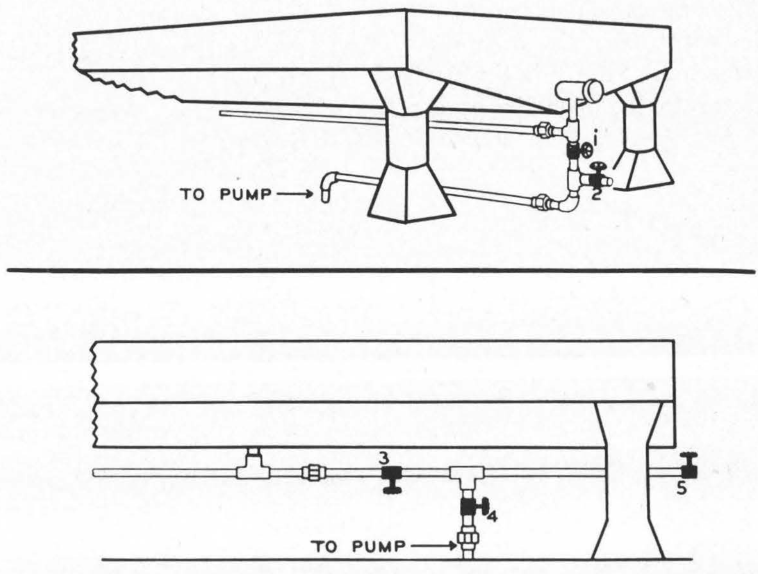

Fig. 7.—Upper section—Bench construction and valve arrangement with inlet located at end of the bench.

Lower section—Bench construction and valve arrangement with inlet located under the bench.

The height of the inner pipe should be no more than the desired solution level in the bench. The diameter of this pipe should be no smaller than 1 inch, with the outside pipe 1½ inches in diameter. The bottom of the outside pipe resting on the bench bottom should be notched or cut in a sawtooth fashion to facilitate entrance of the solution. The solution rises in between the two pipes as the bench is being flooded, and the solution begins to overflow into the central pipe when the bench is pumped to the desired level. The suction of the solution removes all the air underneath the cap, and the siphon action continues until air is sucked in at the bottom of the outside pipe. Complete drainage of the small amount of solution remaining in the bench is through the pump. The longer the pipe extends underneath the bench, the more rapid is the flow of the solution through the siphon.

Valves

Figure 7 indicates the method of manipulating valves when solutions are changed. In the upper diagram of figure 7, for normal operation, valve 1 should be open and valve 2 should be closed. To pump out the tank, valve 1 should be closed and valve 2 opened. In the lower diagram of figure 7, for normal operation, valves 3 and 4 should be opened and valve 5 closed. To pump out the tank, valve 3 should be closed and valves 4 and 5 opened.

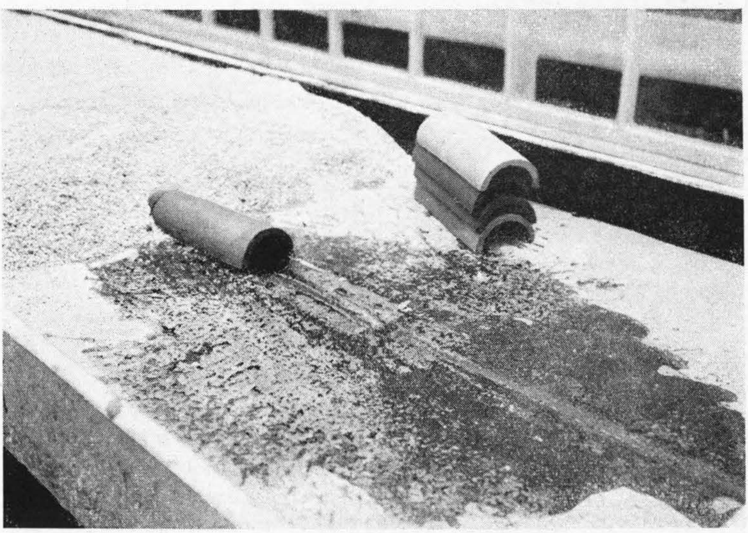

Fig. 8.—Half-tile used as a solution channel. Note the inlet from below the bench in the center of the picture and the notch at the bottom of the concrete in this modified V-bottom bench.

Trough

To obtain rapid spread of the solution in the bench, any one of the following suggested methods is satisfactory: half-tile (fig. 8), eaves troughs with beads removed, or a wooden inverted V. The eaves trough should be asphalted to prevent zinc damage, and wedges should be placed between it and the bench bottom to allow for entrance and exit of the solution. Large cracks or openings should be covered with black iron screen to prevent the medium from clogging the trough.

Pumps

Either a sump or side-suction centrifugal pump can be used for flooding the bench. Sump pumps are the easiest to install. Side-suction types can be placed in a separate compartment so that the suction inlet is only several inches below the solution level when the tank is full, which insures priming, although the end of the inlet pipe must be near the bottom of the tank. For large installations a trash pump, which will not be stalled by pieces of the medium wedging between moving parts, is satisfactory.

Any reliable pump manufacturer has a suitable pump for gravel culture. Some types have a water lubricating mechanism which is not satisfactory for nutrient solutions, and a grease cup should be substituted. A pump with a minimum capacity of 25 gallons per minute with a 10-foot head is the smallest that can be recommended for one 100-foot bench. Pumps of greater capacity will be needed for larger installations.

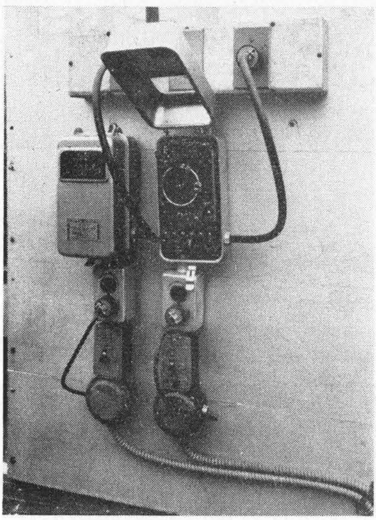

Fig. 9.—Time clocks used for automatic control of the number of pumpings per day.

On all sump pump installations allow a clearance of at least 6 inches from the surface of the solution to the electrical box for slopping of the solution when agitated.

Time Clocks

Electric clocks (fig. 9) ensure regular pumpings. The present empirical recommendations of so many times per day serve the purpose. The following types are available:

Type T-27 Time Switch, Single Pole, Single Throw, General Electric Co., Schenectady, New York. Specify whether 115 V or 230 V clock is desired. Any number of additional "on" and "off" tabs can be secured.

Type K-11 Sangamo Time Switch, Sangamo Electric Co., Springfield, Illinois, is satisfactory if a maximum of three pumpings per day is desired.

MEDIUMS

The most satisfactory material for the growth of plants with the subirrigation method is one that is inert, does not give off any undesirable elements, does not change the pH, retains a sufficiency of water, and does not disintegrate. To date, there is nothing that approximates this ideal so closely as Haydite which can be obtained from several companies:

Hydraulic Press - Brick Co., South Park, Ohio.

Western Brick Co., Danville, Ill.

The Haydite Corp., 32nd and Roanoke Rd., Kansas City, Mo.

Haydite Sales Corp., Rialto Bldg., San Francisco, Calif.

The Cooksville Co., Ltd., 46 Bloor St. W., Toronto, Ontario, Canada.

The B grade of Haydite, composed of a mixture of coarse (three-eights inch in diameter) and fine particles is the most suitable size, although it has been found that finer sizes may be more suitable, particularly when inadequate drainage is provided. Because of the coarseness of the medium, there is a tendency for the roots to form at the bottom of the bench instead of throughout the entire body of the medium. This condition is probably due to excess aeration. The formation of the entire root system at the bottom necessitates complete drainage, else damage may occur to the roots even though a very small amount of solution remains standing (fig. 10 and 11). In finer mediums, root development occurs throughout the medium, and standing solution at the bottom may not cause serious damage.

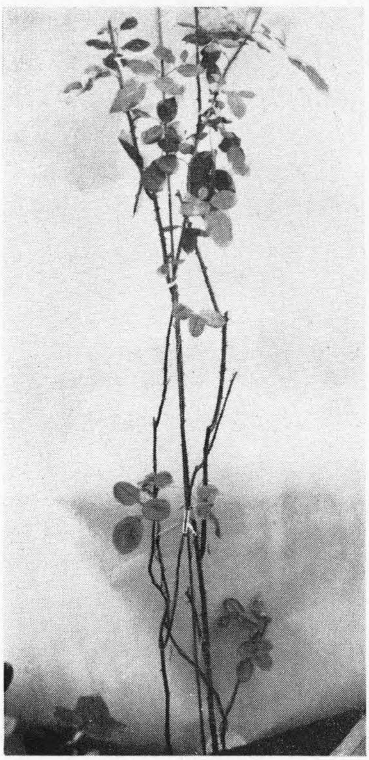

Fig. 10.—A Joanna Hill rose grown in a flat-bottomed bench where water was standing. Note extreme defoliation and chlorosis of leaves near the top of the photograph.

Acid silica gravel is satisfactory as a medium but shipping costs are high because of its weight. The Parry Company, Chillicothe, Ohio, furnishes a $\frac{1}{4}$-$\frac{1}{2}$ inch particle size grade which is most suitable.

Trap rock, granite chips, and other similar materials are suitable if the particle size is approximately $\frac{3}{8}$ inch.

Hard- and soft-coal cinders may likewise be used, although statements about their cheapness should be tempered, since screening and leaching consume time and labor. Cinders vary with the source of coal and in some localities may contain toxic substances. Excess of boron has been found in some localities and if present can be neutralized by the addition of 10 cubic centimeters of commercial sodium silicate to 100 gallons of solution. This addition may be made even after the plants are benched. Some cinders distintegrate readily and may be troublesome because of high water-holding capacity and insufficient aeration. Occasionally cinders are alkaline and may precipitate iron, phosphorus, and manganese. As a precautionary measure, cinders should be leached thoroughly. One-fourth to one-half inch is a suitable size for cinder particles.

Calcareous gravels are suitable for crops that grow satisfactorily in a pH of 7 or above. As a consequence of the high pH, precipitation frequently occurs. Calcareous gravels are particularly unsuitable for roses and gardenias. Particles one-fourth to one-half inch in size are best.

Fig. 11.—Standing water in a flat-bottomed bench—an undesirable environment for optimum plant growth.

Limestone chips can be used in a manner similar to calcareous (lime-bearing) gravel. Slag from blast furnaces should be avoided because of its extreme alkalinity and possible toxic content.

No matter what type of medium is selected, monocalcium phosphate should be broadcast on the surface at the rate of 5 pounds per 100 square feet. This should be watered in. A new or unused medium, particularly the calcareous types, absorbs phosphorus and to prevent the medium from removing the phosphorus from the solution this practice should be observed.

SOLUTIONS

The nutrient elements are supplied to the plants in solution form. Many different formulas have been advocated by various workers but the differences between them are not great and, to save confusion, a solution is given below which has proved satisfactory on many crops:

COMPOSITION OF THE WP* FORMULA

Chemical	Per 1,000 gallons of water
Potassium nitrate	5 lb. 13 oz.
Ammonium sulfate	1 lb.
Magnesium sulfate	4 lb. 8 oz.
Monocalcium phosphate	2 lb. 8 oz.
Calcium sulfate	5 lb.
	18 lb. 13 oz.

* Developed by Arnold Wagner and G. H. Poesch of the Horticulture Department of the Ohio Agricultural Experiment Station.

The chemicals given in the formula can be mixed together in dry form, if desired, as the mixture will not deteriorate and can be stored and used as needed. The WP formula may be purchased ready for immediate use from the Makon Chemical Company, Ann Arbor, Michigan.

It is often difficult to obtain the commercial grade of potassium nitrate and the following modification of the WP formula is suggested:

Chemical	Per 1,000 gallons of water
Calcium nitrate	5 lb.
or	
Sodium nitrate	5 lb.
Potassium chloride	5 lb.
Ammonium sulfate	1 lb.
Magnesium sulfate	4 lb. 8 oz.
Monocalcium phosphate	2 lb. 8 oz.
Calcium sulfate	5 lb.

The chemicals in this latter formula should be weighed out individually and mixed in the tank.

The various grades of superphosphate may be used in place of monocalcium phosphate. Proportionately more must be added because of the lower percentage of phosphorus and the decrease in solubility.

Plants benched in gravel culture should be supplied with a ½ WP solution until new roots develop into the medium, when the strength of the solution should be raised to a 1 WP level. Since root development is usually rapid, the strength of the solution may be increased in 3 to 7 days. When the plants are well established, the solution should be raised to a 2 WP level by adding twice the amount of chemicals per 1,000 gallons of water recommended in the WP formula. The use of a 2 WP solution is not advised on all plants nor at all seasons of the year. This matter is discussed under each specific crop.

The use of a nutrient solution in which ammonium sulfate alone serves as a source of nitrogen has not proved satisfactory with many crops because of the high concentration of ammonium. Additions of ammonium sulfate at 1 pound per 1,000 gallons every 2 weeks on well established, growing plants in spring, summer, and early fall is desirable. However, the pH of the solution must be tested regularly as it tends to drop rapidly, and the nitrate level may rise too high if the plants do not absorb the ammonium, and less frequent additions should be made. The additional supply of ammonium nitrogen is apparently beneficial in inducing the better growth of plants that is usually characteristic of gravel over soil.

Manganous sulfate should be added to all solutions each month. One ounce of manganous sulfate is dissolved in 1 gallon of water acidified with three to five drops of commercial sulfuric acid. All this solution should be used for 1,000 gallons of nutrient solution. Iron should be added weekly in the form of ferrous sulfate at the rate of 4 ounces per 1,000 gallons.

Sources of Chemicals

The chemicals used are of commercial grade and are reasonably priced. Most of them may be obtained from local dealers. Since manganous sulfate is necessary in only small amounts, it can be obtained from a druggist.

Monocalcium phosphate can be obtained from the Monsanto Chemical Company, St. Louis, Missouri, Akron, Cleveland, or Cincinnati, Ohio. The reason for the use of this food-grade material is its low fluorine content. The fluorine may not be as dangerous as originally thought, however, and treble phosphate has been used satisfactorily.

Since the materials used are not chemically pure, they contain the necessary trace elements without additions except those mentioned. Recommendations for adding boron, zinc, copper, and other elements should not be followed without specific advice. Considerable damage has resulted in some cases because of overzealousness. The addition of small amounts of thiourea, tryptophane, liquid manure, indolebutyric acid, sugar, nicotinic acid, or vitamin B_1 has not proved beneficial.

Changing Solutions

The original recommendation called for a change of solutions weekly, but at present no complete change is necessary more frequently than once in 2 months. In some instances, solutions have not been changed for several months, but as a precautionary measure, a change every 2 months is advocated.

Testing Solutions

The Simplex Soil Testing Kit or the LaMotte Soil Testing Kit can be used for general purposes. The Simplex is sold by the Edwards Laboratory, 3295 West 130th Street, Cleveland 11, Ohio, the LaMotte by the LaMotte Chemical Co., Baltimore, Maryland.

The nutrient levels usually maintained in gravel culture are considerably higher than those in soil, and color charts in the test kit instruction booklets are of no value unless the nutrient solutions are diluted before being tested. A quick and accurate method of diluting and testing solutions, together with several precautions, is as follows:

Since small volumes of solutions are used, accuracy is essential, and either 1- or 5-cubic centimeter graduated pipettes are desirable. Medicine droppers used in the tests vary in size, but uniform drops can be obtained by holding the dropper at a 30-degree angle from the horizontal when measuring reagents or solutions. This position reduces the possibility of air bubbles interfering with the drops at the lower end of the dropper. Usually the medicine droppers will deliver 15 drops per 1 cubic centimeter. Knowing the number of drops per cubic centimeter is helpful when high dilutions are made, as it is often convenient to begin with one-half cubic centimeter rather than one.

To insure against contamination, rinsing the equipment with tap water, then distilled water is essential. The placing of a carboy of distilled water on a shelf above the sink where the solutions are tested is desirable. A siphon can be made of a few pieces of glass and rubber tubing and will bring the water within convenient handling distance under sufficient pressure for quick rinsing. A pinch clamp on a short piece of rubber tubing at the lower end of the distilled water line is a convenient shutoff valve.

The nitrate nitrogen levels in nutrient solutions usually vary between 200 and 1,000 parts per million, but the recommended test kit booklets contain color charts only up to 25 parts per million. The nutrient solution must be diluted sufficiently to fall within the range of the color charts. This dilution can be accomplished by placing 1 cubic centimeter of a nutrient solution in one of the small glass vials in the test kits and adding 3 cubic centimeters of distilled water with either a pipette or calibrated medicine dropper. This solution should be mixed thoroughly by shaking.

With reference to figure 12, which is a diagram of a nitrate spot plate, one drop of the diluted nutrient solution should be transferred with a clean medicine dropper to wells No. 1, 2, 3, 7, 8, and 9. With a clean dropper, distilled water should be added in the following order: one drop to well No. 2, two drops to well No. 3, three drops to well No. 7, four drops to well No. 8, and five drops to well No. 9 .The solution in well No. 9 should be mixed thoroughly by running it up and down several times in the dropper by giving the rubber cap a pinch and releasing slowly several times. One drop of the solution in well No. 9 should be transferred to well No. 12. In the same manner of mixing and then transferring, one drop of solution in well No. 8 is taken to well No. 11, one drop of solution in well No. 7 to well No. 10, one drop of solution in well No. 3 to well No. 6, and one drop of solution in well No. 2 to well No. 5. It is not necessary to clean the dropper between each transfer, but it is essential to remove any droplets of solution remaining in the dropper by a quick shake before proceeding to the next well.

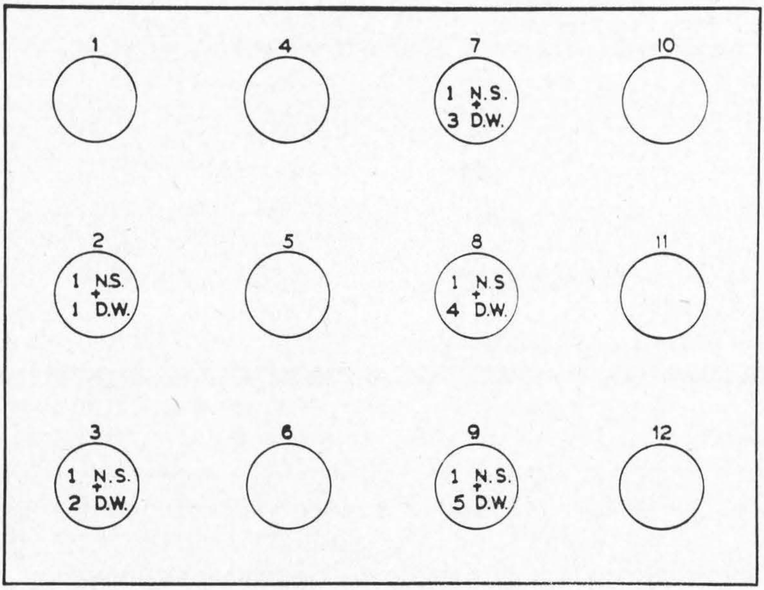

Fig. 12.—A nitrate spot plate. Abbreviations n. s. and d. w. are nutrient solution and distilled water, respectively, and numerals within the circles indicate the number of drops.

The nitrate reagent from the test kit should be added in the correct amount to wells No. 1, 5, 6, 10, 11, and 12. With reference to the Simplex kit, the readings in these wells should be, respectively, 100 parts per million, 200 parts per million, 300 parts per million, 400 parts per million, 500 parts per million, and 600 parts per million. For accuracy, a comparison of the color obtained in the nitrate spot plate should be made only with the highest reading on the color chart, which is 25 parts per million with the Simplex kit. Should the nutrient solution contain more than 600 parts per million of nitrate nitrogen as shown by the presence of a dark blue or bluish-black color in well No. 12, it will be necessary to add more than 3 cubic centimeters of distilled water to the 1 cubic centimeter of nutrient solution. The scale of dilution and the factor for multiplication of the readings in the wells are as follows:

Cc. of Nutrient solution	Cc. of distilled water added	Factor for multiplication of readings in the wells
1	0	1
1	1	2
1	2	3
1*	3*	4*
1	4	5
1	5	6

* Used in the example.

It is essential to use only the reading of 25 parts per million on the nitrate color chart when making comparisons, in order to obtain accurate readings.

The methods of testing for phosphorus and potash are similar to each other except that different reagents are used for each of the tests. The maximum amount of phosphorus that can be read with the color chart of the Simplex system is 5 parts per million, and the maximum of potash is 20 parts per million. Dilution of the nutrient solution is necessary in order to bring the reading within the range of the color chart. This dilution is accomplished by transferring 1 cubic centimeter of nutrient solution to one of the small glass vials in the test kits and adding various amounts of distilled water to the vial. The contents should be shaken to ensure mixing, and all but 1 cubic centimeter discarded before the test is made, as the directions for each of the tests require that only 1 cubic centimeter be used. The scale of dilution and the factor for multiplication of the readings in the vial are as follows:

Cc. of nutrient solution	Cc. of distilled water added	Factor for multiplication of readings in the wells
½	0	*
½	½	2
½	1	3
½	1½	4
½	2	5
½	2½	6
½	3	7
½	3½	8
½	4	9
1	0	1
1	1	2
1	2	3

* It is not possible to use this particular dilution, because the test requires the presence of at least 1 cubic centimeter of solution before it can be made. This was inserted as a guide for a possible error.

The tests for calcium and ammonia usually fall within the limits of the color charts, and no dilutions are necessary. The iron test is not entirely satisfactory and cannot be used as a guide for iron additions. Other tests for nutrients given in the test kit booklets need not be made unless unexplained difficulties arise which are not due to an unbalance of the nutrients for which the tests have been described.

TABLE 1.—Analysis of nutrient solutions in parts per million.

	WP		2WP	
	Calculated	Fresh solution	Calculated	Fresh solution
Nitrates	400	400	800	750
Ammonium	28	25	56	50
Phosphorus	65	60	130	120
Potassium	250	250	500	500
Calcium	310	150	620	250

The analysis of a WP and 2 WP solution is given in table 1. The differences between the nutrient levels of the calculated and fresh solutions are accounted for by precipitation of the nutrients, low solubilities, or inaccuracies of the present quick tests.

Since phosphorus may readily precipitate from the solution or be absorbed by the plant, tests and additions should be made weekly. Nitrate and potassium tests made every other week after changing are sufficient. It is not necessary to test for magnesium unless solutions are infrequently changed. Addition of the full amount of magnesium sulfate every 2 months is advocated. The nutrient levels given in table 2 can be maintained with satisfactory results.

TABLE 2.—Nutrient levels in parts per million.

	WP	2WP
Nitrates	400	600 plus
Ammonium	25	50
Phosphorus	25	40
Potassium	100	200
Calcium	125	200

After the solution is tested, it is necessary to make additions of the deficient nutrients. The amounts of chemicals per 1,000 gallons of water to provide definite parts per million are as follows:

7 pounds of calcium nitrate provide 130 parts per million of calcium and 400 parts per million of nitrates.

4½ pounds of sodium nitrate provide 400 parts per million of nitrates.

5 pounds and 13 ounces of potassium nitrate provide 250 parts per million of potassium and 400 parts per million of nitrates.

1¼ pounds of Uramon (urea) provide 90 parts per million of nitrogen equivalent to 400 parts per million of nitrates.

5 pounds of potassium chloride provide 250 parts per million of potassium.

5 pounds of potassium sulfate provide 250 parts per million of potassium.

1 pound of ammonium sulfate provides 28 parts per million of ammonia.

4½ pounds of magnesium sulfate provide 50 parts per million of magnesium.

2½ pounds of monocalcium phosphate provide 42 parts per million of calcium and 65 parts per million of phosphorus (200 parts per million of phosphate).

5½ pounds of 16 per cent superphosphate provide 65 parts per million of phosphorus (200 parts per million of phosphate).

5 pounds of calcium sulfate provide 145 parts per million of calcium.

The water level in the tank is fully as important as the nutrient level and should be checked daily.

Acidity or pH

The pH of the solution should be checked twice a week without fail. It should be maintained at 6.5 for most crops. Gardenias do best at a pH of 5.5 to 6. Sweet peas, stocks, carnations, gerbera, feverfew, asters, pansies, chrysanthemums, and others will grow satisfactorily in a pH of 7.

To raise the pH, a stock solution of 2 ounces of sodium or potassium hydroxide to a gallon of water should be used, or ammonium hydroxide and water, one part to three, respectively, can be used. To lower the pH, a stock solution of 1 ounce of either concentrated sulfuric or phosphoric acid to a gallon of water should be used.

When any materials are added to a solution, thorough stirring is necessary to obtain proper mixing.

Pumping

The number of times per day the solution should be pumped depends on the type of medium, season, size of plants, and the concentration of the solution. In summer, mature rose plants in a coarse (½- to ¾-inch) medium should be pumped three to four times during the daylight period (7 a.m., 11 a.m., 2 p.m., and 5 p.m.). In winter, pumping should be reduced to once daily or once every 2 days. Carnations should rarely be pumped more than twice daily in summer and once in 2 or 3 days in winter, providing no wilting occurs. Young plants which are not established should be pumped less frequently, as root action is slow. Experience is the best guide, together with a close check of the growth of the plants.

The concentration of the solution exerts some influence on the number of times the bench is pumped per day. The greater the concentration of the solution, the greater the number of pumpings required; and the lower the concentration of the solution, the fewer the number of times the bench is pumped per day. A WP solution would be pumped less frequently than a 2 WP solution on the same crop in the same season of year. During the heat of summer, it will be necessary to pump a WP solution frequently because of the danger of wilting. The reason for the influence of the concentration upon the number of pumpings is not entirely clear, but it appears that greater concentrations inhibit water absorption, and unless the solution is pumped more frequently, growth is checked severely.

The solution should be pumped to within 1 inch of the surface of the medium to prevent the growth of algae (green scum). Pumping the solution higher than the surface of the medium may induce stem diseases which spread rapidly through plants grown in gravel culture. Careful attention should be given to the maintenance of the correct volume of nutrient solution to prevent soluble salts from accumulating on the stem and causing injury. Night pumping is not essential.

PLANTING

Tests during the past years have shown that for most crops, planting with a soil ball may lead to serious difficulties from root and stem rots. The best practice is to place the plants in 2½-inch pots using equal parts of FF Haydite and peat as a medium. Plants so handled should be fertilized weekly with a WP solution applied overhead to the Haydite and peat medium. It is usually necessary to water the plants between fertilizer applications to prevent wilting. Seedlings may also be placed directly in the gravel bench at their final planting distance, but considerable space is occupied with this practice. It is not desirable to transplant seedlings to the bench, setting them closely, later moving them to their permanent planting distance. Although space is saved by this practice, there is a severe check in the growth of the plant. The fewer the number of times the small plants are transplanted, the more satisfactory is their growth. Bulbs are planted so that their "noses" are one-half inch below the surface of the medium. Too deep planting results in rotting, which can be partially overcome by less frequent pumping. Plants should be spaced in gravel similarly to the way they are in soil. Large seed (sweet peas) can be sown directly in the medium.

PEST CONTROL

SPRAYING and FUMIGATION.—The same insects and diseases attack plants in gravel culture as in soil. Since mediums do not contain any organic matter which would act as a buffer, it is necessary to pump the solution into the bench just prior to spraying or fumigating to cover the roots with a film of moisture which protects them. It is not necessary to fill the bench with water and discard it after spraying or fumigating. If the nutrient solution is to be changed, it should be pumped into the bench, the plants should be sprayed or fumigated, and the solution should be discarded. Sulfur dusts or sprays lower the pH of the solution. Azobenzene, cyanide, Parathion, and nicotine fumigation are safe. Insects in the medium may be controlled by flooding the bench to float the insects and then spot-fumigating with nicofume pressure fumigators.

STERILIZING.—Steam sterilization of the bench and medium is the most effective method of controlling diseases and pests, but causes cracking of concrete benches due to expansion and contraction. The medium should be allowed to reach 180° F. for 30 minutes. Because of the development of cracks with steam sterilization, chemicals have been used in some cases. Formaldehyde is prepared by mixing in the tank 1 gallon of commercial formalin to 50 gallons of water. This is pumped into the bench to cover all the medium and should be allowed to remain for 24 hours. The solution should be drained back into the tank and allowed to stand another 24 hours to sterilize the pipes, pump, and tank. Flushing the bench and tank with water until all odor of formaldehyde has disappeared is essential before planting.

Dowacide has been used successfully in the following manner: The bench should be flushed with water to remove the finer particles of materials at the bottom and to clean the medium, and the tank should be flushed and filled with clean water. Place sodium hydroxide in the water in the tank at the rate of 2½ pounds per 1,000 gallons and then add to the tank 2½ pounds of Dowacide to 1,000 gallons of water. Pump this solution into the bench to cover all the medium and let it stand for 24 hours. Then drain the solution back into the tank and let stand for 24 hours to sterilize the pipes, pump, and tank. It is necessary to leach this material from the medium by frequent flushing with water, as it is very toxic to plants. Since the sodium hydroxide precipitates the phosphorus on the surfaces of the particles of medium, it is desirable to broadcast monocalcium phosphate on the medium at 5 pounds per 100 square feet, and wash it in before planting a new crop.

Copper and mercury compounds should not be used for sterilization, as toxicity is apt to result.

SPECIFIC CROPS

The more important greenhouse flowering crops have been grown in gravel culture since 1937. These include roses, carnations, chrysanthemums, gardenias, snapdragons, sweet peas, lilies, iris, narcissus, asters, stocks, Euphorbia, Boston yellow daisies, pansies, feverfew, annual chrysanthemums, calendulas, dahlias, bachelor buttons, and others. A report of these has been given by Kiplinger and Laurie (8). Initial experiments compared growth and production of plants in gravel culture with those in soil. In general, gravel culture was equal to or better than soil for growing plants. The tests in the last few years consisted of improving the techniques of growing plants in gravel culture.

Roses

COMMERCIAL CULTURE.—Dormant-budded or started-eye plants should be benched, preferably in January or February. Own-root stock grown for 1 year in a cloth house, stored in a cooler, and cut back similarly to a started-eye, can be benched at this time. Holding such plants in storage for later benching is detrimental, as the growth that is made is usually unsatisfactory. Because the removal of plants during the winter often upsets the grower's rotation, either grafted or small actively growing own-root stock may be used. The ball of soil on grafted plants should be washed off, taking care not to break any more roots than is necessary. The use of plants with a ball of soil does not always work satisfactorily because the ball of soil retains too much moisture.

Irrespective of the type of plant used, the starting solution should be a ½ WP until the roots begin to develop into the medium. Pumping once in 2 or 3 days during the dark days of winter for the dormant-budded or started-eye plants is sufficient until foliage develops concurrently with the development of the root system. As the plants become well established, pumpings should be increased and the concentration of the solution raised to a WP level. During the good growing seasons (spring and fall) a 2 WP solution can be used. In the warm days of summer, a WP solution pumped 3 to 4 times daily gives best results. With the dark days of winter, the solution concentration can be reduced to a WP nitrogen level, but a 2 WP level of all other components. Such a practice of manipulation reduces the amount of blind wood and thin shoots produced. Additions of ammonium sulfate during spring, summer, and early fall induces better growth on roses. Maintenance of a 2 WP potash level during October and November reduces the blindness on Christmas pinches. A decrease in blindness at Christmas from 50 to 25 percent has been obtained in numerous tests when potassium was applied in the fall.

VARIOUS SOLUTIONS and MEDIUMS.—One of the earliest tests with roses was made to determine the effectiveness of several recommended solutions and several mediums. Dormant-budded "started-eye" plants of Better Times roses were used in this test. They were planted in February 1938. Table 3 shows the production record for 1 year. It will be noted that soil-grown roses produced fewer flowers per plant and poorer grade flowers than those grown in silica gravel or cinders. The differences between solutions used were not significant, but the differences between cinders and the two grades of silica gravel were significant.

TABLE 3. — The production of Better Times roses in various nutrient solutions. Planted February 1938. Recorded to February 1939.

Nutrient solution	Medium	Flowers per plant	Shorts	Percent by grade 9 in.	12 in.	15 in.	18 in.	21 in.	24 in.	27 in.	30 in.
....	Soil	13.0	13	48	19	10	7	2	1	....	....
2 E*	Silica gravel	19.5	11	33	28	17	6	5	....	....	....
2 WP*	Silica gravel	22.0	4	20	31	22	14	6	2	....	1
2 W*	Silica gravel	20.0	3	14	23	25	19	9	6	....	1
2 WP	Fine silica gravel	17.5	7	19	24	28	12	6	4	....	....
2 WP	Coarse cinders	26.0	2	10	24	22	24	12	6	....	....

* For composition of the solution see Appendix tables I and II.

POTASSIUM ADDITIONS.—Since high potassium content is usually recommended for optimum growth and production of roses, a test was made in 1939 to determine the effectiveness of potassium additions. Table 4 shows the effect of increasing the potassium content of 2 WP solution on the production of Lucile Hill rose. It will be noted that again, as in table 3, the production in gravel is higher than in soil and that an increase in the potassium content of the 2 WP solution increases the production over that in the regular 2 WP solution significantly. The WP solution ratio of nitrogen to potassium is about two to one, and it is possible that a change to approximately a one to one ratio might increase the rate of stored carbohydrate utilization during the night and result in the development of a greater number of shoots per plant.

TABLE 4.—The effect of increasing the potassium content in the nutrient solution on the production of the Lucile Hill rose.

Treatment	Flowers per plant	Percent by grade					
		Culls and shorts	9 in.	12 in.	15 in.	18 in.	21 in.
2 WP	17.0	14.7	36.3	30.4	12.7	4.9	1.0
2 WP plus 500 parts per million of potassium	21.3	16.4	36.7	26.6	13.3	4.7	2.3
Soil	12.8	15.8	40.8	27.9	11.7	3.3	.4

GLUCOSE ADDITIONS.—In an attempt to supply additional carbohydrates to roses during cloudy winter weather, Better Times and Happy Days roses were supplied with glucose solutions at concentrations of 1.3, 2.6, and 4.1 percent. No differences in growth could be observed, but considerable difficulty was encountered because of increased bacterial activity at the roots and a subsequent check in growth. This activity was finally controlled by additions of silver as silver nitrate at the rate of one to two parts per million.

TRACE ELEMENT ADDITIONS.—Some workers have recommended the additions of such trace elements as boron, copper, and zinc to nutrient solutions to secure greater growth and development of plants. Table 5 shows the results of such treatments on the Better Times rose. It will be noted that some increases in production were observed from addition of boron and zinc in low concentrations. The additions of copper proved to be detrimental. Since the materials composing the nutrient solutions are commercial in form, they frequently contain some of the trace elements; hence, under such conditions, any additions may be unnecessary and sometimes even detrimental. Certain white varieties of roses, such as Snow White and American Pride, are benefited by additions of boron up to five parts per million.

OCCURRENCE OF TRACE ELEMENTS.—A WP solution with recommended additions of ferrous and manganous sulfates was flushed through C grade Haydite, and a 500-cubic centimeter sample was taken for spectrographic analysis. Although the relative amounts of the mineral elements present cannot be determined accurately by this method of analysis, minute quantities can be detected readily. The following minerals were found in their estimated order of decreasing concentrations: calcium, potassium, magnesium, silicon, sodium, iron, aluminum, titanium, copper, manganese, and vanadium. With the presence of these trace elements in the solution, either from the fertilizer-grade chemicals or the Haydite, their addition would appear unwarranted unless a deficiency occurs.

TABLE 5.—The effect of various concentrations of boron, copper, and zinc on the production of Better Times roses. Planted January 2, 1939. Recorded to August 8, 1939.

Additional treatment	Basic solution	Flowers per plant	Percent by grade						
			Culls and shorts	9 in.	12 in.	15 in.	18 in.	21 in.	24 in.
1 part per million of boron (later 5 parts per million)	2 WP	14.7	14.8	19.3	29.6	21.6	11.4	2.3	1.1
2 parts per million of boron (later 10 parts per million)	2 WP	14.2	7.1	32.9	23.5	28.2	7.1	1.2	....
1 part per million of zinc (later 10 parts per million)	2 WP	14.7	4.6	36.4	30.7	21.6	4.6	2.3	....
2 parts per million of zinc (later 50 parts per million)	2 WP	15.3	34.8	45.7	15.2	4.4	....	....	....
1 part per million of boron and zinc (later 5 and 10 parts per million, respectively)	2 WP	16.3	21.4	39.8	21.4	12.3	5.1	....	....
2 parts per million of boron and zinc (later 10 and 50 parts per million, respectively)	2 WP	11.3	20.6	38.2	32.4	5.9	2.9	....	....
56 parts per million of ammonia added weekly	2 WP	10.7	9.4	10.9	35.9	14.1	17.2	9.4	4.7
Check plot	2 WP	12.0	6.9	29.2	27.8	23.6	8.3	4.2	....
1 part per million of copper (later 25 parts per million)	2 WP	10.5	20.6	31.8	19.1	17.5	9.5	1.6	....
....	2 W*	8.5	11.8	23.5	29.4	19.6	9.8	5.9	....

* For composition of the solution see Appendix tables I and II.

SOURCES OF NITROGEN.—The source of nitrogen has been a controversial subject for many years. An attempt was made to determine the correlation between the plant growth during the winter months and the source of nitrogen supplied in the nutrient solutions. A WP solution with potassium nitrate and ammonium sulfate was used as a control, and the following chemicals were used alone as a source of nitrogen: ammonium sulfate, ammonium nitrate, sodium nitrate, and calcium nitrate. Each material was substituted in the original WP solution in amount equivalent to a 400 parts per million nitrate nitrogen level.

Nitrate tests during the months of November and December indicated an accumulation of nitrates in the solutions containing high ammonium which reached its peak 15 to 18 days after the application of the solutions. A comparison of the results of the use of ammonium sulfate and ammonium nitrate showed that the peak of nitrate accumulation was reached when all the ammonium disappeared from the solutions.

The growth of rose plants in the ammonium nitrate solution practically stopped when the pH reached 5.5 or lower. The same was true in the ammonium sulfate plot. The injury did not manifest itself upon the roots, but produced a yellowing of foliage, an almost complete drop of leaves, and subsequent failure of new auxillary buds to develop. It may be assumed that the high hydrogen-ion concentration of the solution indirectly affected the nitrate reduction process and the ammonium accumulation.

TIME OF PLANTING.—The usual procedure in commercial rose growing is to plant dormant-budded stock from January until April or May. Since the vitality of such stock is depleted in storage, a test was made to determine the comparative production between Happy Days roses planted in January and similar roses kept in storage at 40° F. and planted in March. Table 6 shows a very significant difference in favor of the earlier planting.

TABLE 6.—A comparison of 1 year's production of Happy Days roses at 60° F. planted in January and March.

Medium	Planting date	Flowers per plant	Percent culls and shorts	Percent 9 to 12 inches	Percent 12 inches plus
Silica gravel	March 22, 1939	10.4	2.3	14.4	83.3
FF Haydite	March 22, 1939	14.8	8.3	27.2	64.5
C Haydite	March 22, 1939	11.0	13.5	15.1	71.4
C Haydite	January 22, 1939	36.1	21.9	15.9	62.2

"DRYING OFF" VERSUS CUTTING BACK GRADUALLY.—The commercial rose grower rests his roses during the summer by the simple process of reducing the moisture at the roots for a week or two and then cutting the plants back, or he may reduce the moisture in the soil slightly and gradually cut his plants back stem by stem until a short, uniform height is obtained. In gravel culture, similar results can be obtained by withholding the solutions during the "drying" periods. After several different tests were made, the results showed the following procedure desirable: When the roses are ready for the rest period in the summer, the solution is withheld until the more succulent stems show signs of wilting, usually in about 3 days. At that time, the medium is flushed with clear water to bring about turgidity, and again the solution is withheld until wilting. A repetition of this drying will result in a rest period of 9 to 10 days. Then a ½ WP solution is applied until new root action develops. If gradual cutting back is desired, it can be done similarly to the process in soil by reducing the number of pumpings of the solutions. The results of these tests showed that production was similar with either method.

RED SPIDER CONTROL.—To avoid the necessity of using spray materials, tests were made to determine the efficiency of the monthly inclusion of selenium in the solution as a toxic agent to mites. Chemically pure sodium selenate (Na_2SeO_4) was used at concentrations of selenium varying between 2½ to 12½ parts per million on Better Times and Peter's Briarcliff roses. The higher concentrations provided up to 47 percent control, which is insufficient for practical purposes. Pyrethrum, timbo, and derris were ineffective when applied in solutions at 0.025 percent.

PRODUCTION.—The usefulness of such a new process as growing roses in gravel depends upon a profitable production. In table 7 are the results of a 2-year test in which a number of commercial varieties were grown on a sufficiently large scale to make results significant. These roses were "carried through" in the usual commercial manner by cutting back gradually with a knife during the late spring season. Very little pinching was practiced, and with the maintenance of a high humidity, especially during the spring and summer, the production of flowers per plant and the number of flowers with stems over 12 inches long are exceptionally high. In many cases the differences between soil and gravel are significant, and the production in soil is equal to that of the average commercial grower. Lowered production in the modified V-bottom bench was due to exceptionally heavy pruning and a 3-week storage period at 40° F. during the time the existing flat-bottomed bench was converted to a modified V-bottom with a slope of 1½ inches from side to center.

FLOWERS PER PLANT.—Table 8 shows a 3-year production record of a number of different commercial varieties of roses grown on a large scale. It will be noted that the production during the third year does not decrease in gravel culture as compared with soil. Usually in the average commercial rose range, the decrease in soil is greater than that which occurred here. This maintenance of high production is undoubtedly due to better aeration of the gravel medium over that of the soil. The decrease in the production of flowers by the plants in Haydite in the modified V-bottom bench from 1940-1941 was due to the presence of solution standing on the bench bottom before the bench was converted from a flat bottom to a modified V. The conversion was made in February 1940, and the plants were stored for 3 weeks at 40° F. during the alteration.

In table 9 is shown the average of the 3 years' production for the plants in table 8. It is clear that plants grown in gravel culture averaged higher in production than similar plants in soil. The differences were striking in both tables 8 and 9, yet the production in soil would equal that of the average grower.

TABLE 7.—A comparison of 2 years' average production of roses in flat and V-bottom benches in soil and V-bottom benches in gravel.

Planted February 1, 1940; recorded to February 1, 1942.

Variety	Type of plant	Soil, V-bottom bench				Haydite, V-bottom bench				Haydite, modified V-bottom bench				Soil, flat-bottomed bench			
		Flowers per plant	Pct. culls and shorts	Pct. 9 to 12 inches	Pct. 12 inches plus	Flowers per plant	Pct. culls and shorts	Pct. 9 to 12 inches	Pct. 12 inches plus	Flowers per plant	Pct. culls and shorts	Pct. 9 to 12 inches	Pct. 12 inches plus	Flowers per plant	Pct. culls and shorts	Pct. 9 to 12 inches	Pct. 12 inches plus
Better Times	Own root	27.8	4.2	10.4	85.4	37.4	5.1	6.8	88.1	33.5	3.9	9.8	86.3	25.5	2.7	13.1	84.2
Better Times	Started eyes	25.4	3.1	5.3	91.6	36.4	4.3	7.6	88.1	28.4	3.5	7.2	89.3	34.2	2.7	8.6	88.7
Better Times	Grafted	23.7	2.8	7.0	90.2	32.9	2.0	4.5	93.5	......	....	....	......	25.1	3.2	11.6	85.2
Happy Days	Started eyes	24.7	6.2	6.6	87.2	37.8	6.8	6.6	86.6	......	....	....	......	30.0	6.9	8.3	84.8
Peter's Briarcliff	Started eyes	22.5	3.4	4.0	92.6	34.5	7.1	5.9	87.0	25.2	7.2	8.8	84.0	27.9	6.9	8.9	84.3
Lucile Hill	Started eyes	23.3	1.1	6.9	92.0	35.5	1.2	8.7	90.1	24.4	1.1	10.2	88.7	30.2	.4	7.1	92.5
Joanna Hill	Started eyes	23.4	.7	5.7	93.6	29.9	1.1	5.6	93.3	23.6	.3	2.5	97.2	31.4	1.4	7.7	90.9

TABLE 8.—A 3-year comparison of the production of flowers per plant of roses in flat and V-bottom benches in soil and V-bottom benches in gravel.

Planted February 1, 1939; recorded to February 1, 1942.

Variety	Type	Soil, ground bench, deep V-bottom			Haydite, deep V-bottom			Haydite,* modified V-bottom			Soil, raised bench, flat bottom		
		1939-40	1940-41	1941-42	1939-40	1940-41	1941-42	1939-40	1940-41	1941-42	1939-40	1940-41	1941-42
Better Times	Own root	12.6	25.1	20.6	31.8	38.0	36.8	23.5	27.2	39.7	13.7	27.4	23.6
Better Times	Started eyes	15.9	25.7	25.1	29.3	35.7	37.1	22.6	24.8	31.9	15.4	32.3	36.1
Better Times	Grafted	15.8	25.3	22.0	25.5	32.5	33.3	......	......	......	13.5	26.6	23.5
Happy Days	Started eyes	14.5	25.5	23.0	28.2	38.0	37.5	......	......	......	16.3	30.3	29.8
Peter's Briarcliff	Started eyes	12.6	23.2	21.7	23.6	33.9	35.0	24.5	21.3	29.1	14.9	30.6	25.3
Lucile Hill	Started eyes	15.1	24.2	22.5	32.1	35.7	35.4	29.9	24.9	23.9	14.8	32.5	27.8
Joanna Hill	Started eyes	15.8	25.3	22.5	35.9	29.9	29.8	24.4	19.4	27.7	16.4	33.1	29.6

* Bench changed from a flat bottom to a modified V-bottom (1½-inch slope from side to center) in February 1940. Plants were removed, stored at 40° F. for 3 weeks, and replanted on February 21, 1940. This operation accounts for the lowered production in this bench for the period during 1940-1941.

TABLE 9.—A comparison of a 3-year average production of flowers per plant of roses in flat and V-bottom benches of soil and V-bottom benches in gravel. Planted February 1, 1939; recorded to February 1, 1942.

Variety	Type	Soil, ground bench, deep V-bottom	Haydite, deep V-bottom	Haydite,* modified V-bottom	Soil, raised bench, flat bottom
Better Times	Own root	19.4	35.5	30.1	21.5
Better Times	Started eyes	22.2	34.0	26.4	27.9
Better Times	Grafted	21.0	30.4	......	21.2
Happy Days	Started eyes	21.0	34.5	......	25.5
Peter's Briarcliff	Started eyes	22.5	30.8	24.7	23.6
Lucile Hill	Staıted eyes	20.6	34.4	26.2	25.0
Joanna Hill	Startde eyes	21.2	31.8	24.1	26.3

* Bench changed from a flat bottom to a modified V-bottom (1½-inch slope from side to center) in February 1940.

SEASONAL AVERAGE.—One of the numerous cultural difficulties with roses in soil is the slowing down of the productiveness of the plant during the winter months. Tests were run over a 2-year period to compare the seasonal production of several commercial varieties in both soil and gravel culture. The months selected for the seasons were as follows: for spring—March, April, and May; for summer—June, July, and August; for fall—September, October, and November; and for winter—December, January, and February. The results of this test are shown in table 10.

The production of flowers by the plants does not slow down in winter in gravel culture any more than in soil. In fact, the increase in production with the gravel-grown plants holds its proportion to the soil over the entire yearly period. Table 10 also indicates that in central Ohio with both soil and gravel culture, approximately one-third of the production is obtained between November and April, at which time the greatest economic returns for roses are secured.

TABLE 10.—A comparison of the production in flowers per plant of roses in soil and gravel culture during various growing seasons.
Planted February 1, 1940; recorded to February 1, 1942.

Variety	Type	Soil, ground bench, deep V-bottom				Haydite, deep V-bottom				Haydite,* modified V-bottom				Soil, raised bench, flat bottom			
		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
Better Times	Own root	4.3	7.4	7.4	3.6	6.6	12.6	12.5	5.6	7.2	11.4	12.4	5.9	3.4	8.5	8.4	3.3
Better Times	Started eyes	4.9	7.9	8.4	4.1	6.0	12.4	12.6	5.3	5.7	9.9	9.7	5.8	4.2	10.1	9.2	4.0
Better Times	Grafted	4.4	7.6	7.8	3.8	6.3	11.6	10.0	4.9	....	......	......	....	3.6	9.7	9.1	4.1
Happy Days	Started eyes	4.7	7.7	8.4	3.4	6.5	13.0	12.8	5.4	....	......	......	....	4.4	11.2	10.6	3.9
Peter's Briarcliff	Started eyes	4.2	7.1	7.3	3.9	5.9	11.6	11.1	5.7	4.2	8.9	8.9	5.3	3.3	10.5	9.3	4.5
Lucile Hill	Started eyes	3.6	7.5	8.3	3.8	5.6	11.8	12.9	4.8	4.9	10.6	11.5	5.3	3.5	11.3	10.1	4.4
Joanna Hill	Started eyes	3.3	9.3	8.2	3.1	3.9	11.9	9.6	3.9	4.8	9.3	7.9	3.2	4.1	14.6	11.3	4.2

* Bench changed from a flat bottom to a modified V-bottom (1½-inch slope from side to center) in February 1940.

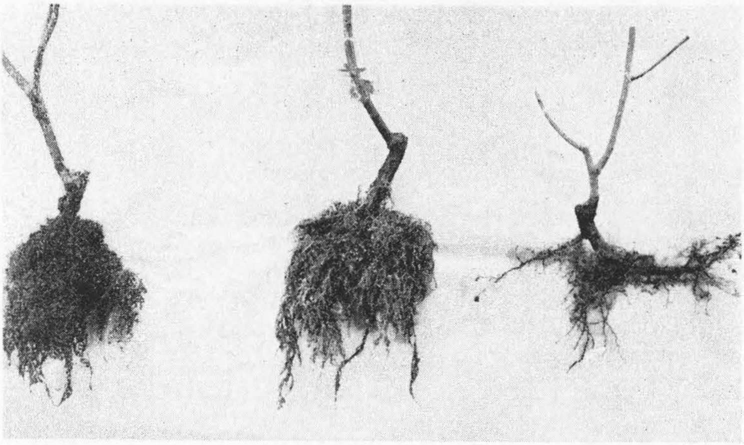

Fig. 13.—Root systems of Better Times roses. Left to right—WP in cinders, WP in silica gravel, soil.

DRAINAGE IN BENCHES.—Reference has been made to the conversion of an existing flat-bottomed bench to a modified V-bottom. It was found that roses grown in flat-bottomed benches were not equal in growth and production to those grown in V-type benches. Careful examination disclosed that irregularities of the floor of the flat-bottomed bench made perfect drainage of the solution back into the tanks impossible. In the V-type bench, any standing solution remains under the half-tile in the center and does not come in contact with the roots. Emphasis of this feature resulted in greater perfection of growth in several commercial establishments where recommendations for the change were followed.

TEMPERATURE RELATIONS.—Many varieties of roses are usually grown at a night temperature of 58 to 60° F. It has often been suggested, however, that at lower temperatures, such varieties as Better Times, Peter's Briarcliff, Joanna Hill, and others would produce better quality but fewer flowers per plant. Since a difference of 3 to 5° F. means a considerable saving in fuel, tests were made to determine whether or not lower temperatures of the air combined with warming of the solution would produce responses comparable to those obtained by growing such roses in the higher temperature. One house was held at the usual night temperature of 60° F., and the other house was held at a night temperature of 56° F., but the solution was maintained at 85° F. When this solution was pumped into the bench, it dropped to a temperature of 70° F. No appreciable differences in production or quality were obtained; as a consequence either method could be used.

ZINC TOXICITY.—Symptoms of zinc toxicity were observed in roses whenever galvanized stakes used for support were inserted into the medium. Painting of inserted ends with emulsified asphalt eliminated this difficulty.

LEAF DROP.—Frequently in both soil and gravel, the check in growth brought about by defoliation of varying severity is serious. Although no effective preventives of leaf drop have been developed, observances of several precautionary measures will minimize its injurious effects. Unnecessary variations in moisture of the medium which make it either too wet or too dry bring about leaf drop from the loss of roots. Mulching roses in gravel culture in hot weather with sphagnum moss, excelsior, glass wool, or some other relatively inert material may aid in preventing excessive leaf drop. Maintenance of high humidity during spring and summer prevents rapid fluctuations in the moisture content of the plant and the medium and also results in longer stemmed flowers. Shading the glass during spring and early summer aids in the maintenance of humidity, as well as in reducing the temperature.

Carnations

COMMERCIAL CULTURE.—The growing of carnations in gravel culture is limited to those varieties which are resistant to the bacterial wilt disease. This organism, which is inside the plants, spreads rapidly throughout susceptible varieties in gravel culture and a complete loss of the entire planting of these varieties may be expected. Because of this, care should be taken to rogue any plants which are not healthy in appearance. Cleaning up infected stock plants requires times and rigorous selection.

Resistant varieties may be handled for gravel culture exactly the same as plants grown for soil. Rooted cuttings are grown in soil, the plants taken to the field in April, dug in July, and benched in gravel. The soil should be washed from the roots of the plants prior to benching to reduce the accumulation of soil in the growing medium. This method of culture has given satisfactory results but is somewhat laborious.

As an alternative, the rooted cuttings may be benched in winter, spaced 4 inches by 4 inches. In April or May every other row is removed and planted in other benches. It is also feasible to grow the young plants in plant bands or 3-inch pots in a mixture of 1 part peat and 1 part FF Haydite. A WP solution is applied by the overhead method each week until the plants are benched in April or May. This early planting enables the grower to establish his plants in good growing weather and considerably more flowers per square foot will be produced in either gravel or soil.

Carnations in gravel are not pumped as often as roses or gardenias, even in warm summer weather. Seldom are more than two pumpings per day necessary. In the fall the pumpings should be reduced to once daily or once every other day. In winter, pumping once in 4 or 5 days is best. Additions of ammonium sulfate should be made in spring, summer, and fall when the plants are well established. A 2 WP solution is used in fall and spring when growing conditions are optimum but during the winter and summer a WP solution is used. A 2 WP potash level during November, December, and January encourages stiff stems. Plants may be carried through for 2 years in gravel the same as in soil.

TABLE 11.—Production of carnations in soil and gravel culture. Recorded October through June.

Variety	Flowers per square foot Soil	Haydite
King Cardinal	24	30
Olivette	30	32
Charm	22	22
Miller's Yellow	19	22
Tom Knipe	24	34
Arundel	19	25

Table 11 shows significant differences in production between soil and gravel culture. Greater quality and stiffness of stem may be expected in gravel-grown plants, provided that during the fall and winter months, pumpings are reduced to a minimum.

Spread of stem and root rot induced by fungus organisms occurs as rapidly in gravel as in soil. Pumping the nutrient solution over the surface of the medium moistens the stem of the plant and encourages the development of such diseases. The maintenance of a pH of 6.5 and a calcium level of 200 parts per million or more reduces the losses caused by bacterial wilt.

Some of the varieties resistant to bacterial wilt are Olivette, Joan Marie, Tom Knipe, Puritan, Dairy Maid, Peter Fisher, Dark Pink Fisher, Derigo, Marchioness of Headfort, Seth Parker, White Fisher, John Briry, and Dimity.

Chrysanthemums

COMMERCIAL CULTURE.—Tests with chrysanthemums conducted each year show that little difficulty will be experienced in growing this crop in gravel culture. The best results are secured by benching the rooted cuttings directly from a propagation bench rather than washing soil from potted plants, as the injury to the root system from this practice checks the growth.

Frequent overhead syringing of the rooted cuttings during the first week after benching aids in their becoming established plants. A WP solution pumped once daily in cloudy weather and twice daily in warm sunny weather is recommended immediately after benching. When the plants are well established, a 2 WP solution should be used with three to four pumpings daily, depending upon the growth of the plants. In the fall, a reduction of two pumpings may be necessary unless foliage development is exceptionally heavy. Figure 14 shows the development of Silver Sheen chrysanthemums in gravel culture.

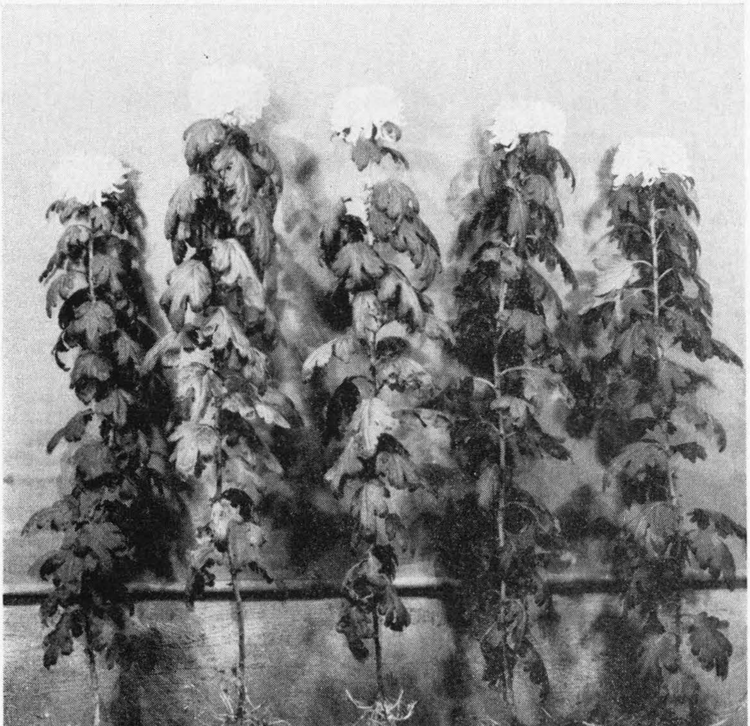

Fig. 14.—Silver Sheen chrysanthemum grown in soil (far left) compared with those grown in silica gravel with various solutions. Note the larger leaves developed in gravel.

Snapdragons

COMMERCIAL CULTURE.—Seedling snapdragon plants may be benched directly to gravel culture, though this method requires occupation of the bench for a considerable time when the small plants are developing. As an alternative, the seedlings may be pricked off to flats or 2½-inch pots in a medium of equal parts of FF Haydite and peat and watered weekly with a WP solution. The plants are benched allowing as much of the haydite and peat mixture to adhere to the roots as possible to reduce root injury. A ½ WP solution is used until the plants are established, and then the concentration should be raised to a WP strength. Higher concentrations induce development of side shoots and a grassy, succulent growth results. Pumping once daily in winter and twice daily in spring is recommended.

AMMONIUM ADDITIONS.—It has been thought that the presence of ammonium nitrogen in the nutrient solution has an inhibiting effect upon the growth of snapdragon plants. The WP solution (28 parts per million of ammonium) and the W solution (ammonium absent) were employed to determine the influence of ammonium nitrogen in the nutrient solution on growth and production. The results, shown in table 12, fail to show any inhibiting effect from the ammonium nitrogen.

TABLE 12.—The influence of ammonium nitrogen on the production of the Christmas Cheer snapdragon.

Medium	Solution	Stems per plant	Stem length, inches	Spike length, inches
C Haydite	WP (28 parts per million of ammonium)	8.3	25.0	6.3
C Haydite	W (ammonium absent)	8.1	23.5	5.2
Calcareous gravel	WP (28 parts per million of ammonium)	8.8	24.1	5.5
Calcareous gravel	W (ammonium absent)	8.2	24.1	5.3

The differences between the plants grown on the WP and W solutions were small. The WP solution produced less than one stem more per plant. The differences in stem and spike length were negligible. Although the plants with ammonium were a darker bluish-green during periods of cloudy weather in winter, this color faded to normal green as the intensity and duration of sunlight increased.

Gardenias

COMMERCIAL CULTURE.—The management of gardenias in gravel culture is not difficult if close attention is given to the maintenance of an optium pH of the solution, the frequent additions of iron, and provision for bottom heat in winter.

Plants may be benched in April or May from $2\frac{1}{2}$- or 3-inch pots of peat or peat and sand. It is not necessary to wash this off the roots. A $\frac{1}{2}$ WP solution is pumped once daily until root action is strong, then the concentration should be raised to a WP level with increased pumpings to prevent wilting. During the summer, a 2 WP solution is pumped 2 or 3 times daily. Frequent overhead syringing is necessary in spring and summer, the same as with soil-grown plants, to maintain optimum humidity. The pH should be maintained at 5.5 for best results. Weekly additions of iron sulfate aid in maintenance of this pH and supply the necessary iron to the plants.

Setting buds for a Christmas crop in central Ohio by lowering the night temperature in 58-60° F. in August and early September is difficult. Carrying the plants on the dry side or increasing the concentration of the solution is dangerous practice, even in the hands of an expert, as root injury induces chlorosis. In addition, these latter practices have never resulted in a satisfactory bud set for a Christmas crop. Shading the plants daily with black sateen cloth from 5 p.m. to 7 a.m. from July 21 to August 13 sets the buds which flower at Christmas. This shading is also satisfactory for soil-grown plants. Two-year plants usually develop a Christmas crop, but they too may be shaded to increase the crop.

Lowering the concentration of the solution to a WP level in late fall and winter prevents the plants from becoming hardened. Confined bottom heat under the benches aids in maintaining a dark green color of the leaves during the winter. Lack of sufficient bottom heat results in chlorosis that cannot be overcome even when the pH is 5.5 and iron sulfate is added regularly. Chlorosis may also be induced by overpumping, high pH, canker, and nematodes, all of which interfere with root action and absorption of nutrients. A night air temperature over 65° F. will cause a serious check in growth.

The plants may be cut back in spring similarly to plants in soil, but the solution should be reduced to a WP level and pumpings are reduced to compensate for loss of foliage. When sufficient foliage develops, a 2 WP solution pumped more frequently is recommended.

SOLUTION VARIATIONS.—Several solutions were used in C Haydite and silica gravel on gardenias. The production is shown in table 13 and figures 15 and 16. The WP solution was superior to either the 2 D or 2 E with *Gardenia veitchii,* possibly because of the high nitrogen levels in relation to the low phosphorus in the Purdue solutions. Belmont types were not affected by the nutrient balance; their production was slightly higher with the 2 D solution. In silica gravel, the WP solution gave higher production on both *veitchii* and Belmont-type gardenias than the New Jersey solution. The latter solution has a very high nitrogen and phosphorus content in relation to the potassium.

Fig. 15.—Root development in Belmont-type gardenias in various solutions. Left to right—2 D Purdue, 2 E Purdue, WP Ohio, and New Jersey. Note the large numbers of white roots on all except the New Jersey solution, which contained a high nitrogen level.

Fig. 16.—Root development on Belmont-type gardenias in various mediums with a WP solution. Left to right—silica gravel, calcareous gravel, C grade Haydite, and cinders. Poor root system on calcareous gravel due to an alkaline medium. Note the development of white roots on the other three mediums.

TABLE 13.—Production of gardenias in C Haydite and silica gravel in various nutrient solutions.

Nutrient solution	Medium	Flowers per plant	
		Veitchii	Belmont type
Ohio WP	C Haydite	32.5	23.5
Purdue 2 D*	C Haydite	12.2	27.0
Purdue 2 E*	C Haydite	13.6	23.0
Ohio WP	Silica gravel	27.6	18.6
New Jersey*	Silica gravel	21.6	13.0

* For composition of the solution see Appendix tables I and II.

PRODUCTION RECORDS.—Although the growing of gardenias in gravel culture may not result in significantly greater production than growing in soil, more flowers of a larger diameter were secured, as indicated in table 14. These 2-year-old plants were cut back in May 1941, and both were grown in the usual commercial manner.

TABLE 14.—The production of 2-year-old *Gardenia grandiflora*, Belmont type, in cinders and soil. Planted May 29, 1940; recorded to May 30, 1942.

	Cinders	Soil
Flowers per plant	61.2	54.1
Diameter of flower, inches:		
Over 4	67.3	43.2
3 to 4	31.6	54.1
Culls	1.1	2.7

Asters

COMMERCIAL CULTURE.—All containers and mediums should be sterilized for asters as Fusarium wilt will kill most of the wilt-resistant varieties offered to the trade. The seedlings should be placed in 2½-inch pots in equal parts of FF Haydite and peat to reduce root injury when the plants are benched. The plants should be fertilized weekly with a WP solution by overhead applications. The plants are generally benched in late fall or winter for a spring crop and they must be lighted to secure earliness in flowering. Pumpings should be made daily with a WP solution after benching until the growth requires a 2 WP solution with increased pumpings. Control of leafhoppers and aphids prevents the spread of the yellows disease.

Lilies

COMMERCIAL CULTURE.—Lilies respond satisfactorily in gravel when the bulbs are planted in the medium so that the tips are close to the surface. Since this planting practice causes longer occupation of the bench than is profitable, a new scheme was devised. The bulbs can be planted in shallow flats, watered with a WP solution, and then the flats racked one on top of another in any cool place or under a bench. It is necessary to maintain a uniform moisture content of the medium in the flat by additional applications of the WP solution. As soon as growth of the tops develops the flats are plunged into benches filled with inert medium, and the benches are then pumped regularly. Table 15 shows the results of such treatment.

TABLE 15.—Lily production in gravel culture at 50° F.

Type		Flowers per stem	Stem length, inches	Number of days to mature
L. Giganteum	Benched December 6	5.1	33	150
L. Erabu	Benched January 12	5.8	32	101
L. Erabu	Flatted February 7 Benched February 28	4.9	33	93
L. Erabu	Flatted March 9 Benched March 29	3.5	32	97

In general, stronger stems and larger flowers can be expected from plants grown in gravel than from those developed in soil. In the absence of *L. giganteum*, the Creole, Mexican, Floridi, and other suitable cut-flower types of lilies may be grown.

PRODUCTION.—Table 16 shows the results of successive plantings of southern- and northern-grown *Lilium giganteum*. These bulbs were planted directly in the bench and pumped with a WP solution. It will be noted that only insignificant differences appear between gravel- and soil-grown plants.

TABLE 16.—Production of lilies in soil and various mediums in nutrient solutions.

Date planted	Type	Medium	Salable flowers per stem	Blasted flowers per stem	Stem length, inches	Days to maturity
February 15	Southern	Soil	4.0	0.5	24.0	109
	Southern	Silica gravel	4.8	1.3	32.0	105
	Northern	Soil	2.8	.3	21.0	109
	Northern	Silica gravel	3.0	.5	28.0	105
March 30	Southern	Soil	2.5	.0	20.0	84
	Southern	Silica gravel	3.0	.3	20.5	84
	Northern	Soil	1.6	.0	17.0	84
	Northern	Silica gravel	1.6	.0	17.5	84
April 18	Southern	Soil	2.1	.1	20.0	75
	Southern	Silica gravel	3.0	.2	27.5	75
	Southern	Cinders	3.2	.3	28.5	75
	Southern	Limestone	2.8	.1	28.5	75
May 16	Southern	Soil	2.0	.0	23.0	70
	Southern	Silica gravel	2.3	.0	24.5	69

Fig. 17.—Lilies in silica gravel.

Stocks

COMMERCIAL CULTURE.—Stocks can be grown successfully in gravel, but careful attention must be given to several details. Seed can be sown directly in the bench, and the plants later thinned to reduce spindly growth. The plants removed in the thining process should not be used as additional planting material, because they usually fail to grow in a satisfactory manner, probably because of injury to the roots. Although direct seeding causes a long period of occupation of the bench, it can be used. A sprinkling of some fine material, such as sand or AAA Haydite, should be placed in the row to aid in maintaining moisture for germination and early growth. Transplanting with a ball of soil from a pot may lead to considerable root and stem rot.

COMPARISON OF SOIL AND GRAVEL.—Before it was discovered that complete drainage was necessary, many experiments were conducted to determine the comparative production of plants grown in gravel culture and in the commercial manner in soil. The results on stocks grown in a flat-bottomed bench in a WP solution are shown in table 17.

In spite of the adverse conditions of poor drainage in gravel culture with a flat-bottom bench, longer stems and flower spikes were obtained in nutrient solutions than in soil.

TABLE 17.—Production of Lilac Lavender stocks in soil, cinders, and silica gravel.

Medium	Number cut		Stem length, inches	Spike length, inches
	Doubles	Singles		
Soil	36	60	16	4.5
Cinders	52	54	22	5.5
Silica gravel	51	54	19	6.0

Sweet Peas

COMMERCIAL CULTURE.—Of the various methods of germinating the seed of sweet peas, none was more satisfactory for fall and winter sowing than planting the seeds in the row about 1 to 1½ inches deep directly in the medium in which they were to be grown. The medium was then flooded with a ½ WP solution and kept slightly on the dry side until the young plants appeared. Too dry a medium will result in death of plants from dessication, and a wet medium promotes rot. Pumping is increased to two periods per day after the plants show signs of vigorous growth. Summer sowing of peas has been variable in results, and it is assumed that the medium becomes too dry and hot, so that the young plants wither quickly. A mulch of excelsior may overcome this difficulty. Manipulation of nutrition during cloudy winter weather is easily accomplished by varying the amounts of the different elements in the solution.

COMPARISON OF SOIL AND GRAVEL.—Difficulties encountered in the commercial culture of sweet peas in soil are numerous. Production data compiled in table 18 show that there is an advantage in growing sweet peas in gravel. Increasing the concentration of the nutrient solution to the 3 WP level caused a drop in production and shortening of the stems. The highest production and best quality were obtained by the use of a 2 WP concentration.

TABLE 18.—The effect of growing sweet peas in calcareous gravel with various nutrient solutions.

Method of Culture	Stems per foot of row
Soil	144
Gravel culture	
WP	150
2 WP	178
3 WP	140
New Jersey (carnation)*	163
2D*	158

* For composition of the solutions see Appendix tables I and II.

MEDIUMS TEST.—Since a neutral or slightly alkaline soil is desirable for the commercial culture of sweet peas, a test was made to determine the most suitable medium for growing peas in gravel culture. The acidity of the 2 WP solutions for each medium was adjusted twice weekly with sodium hydroxide to a pH of 7.0 to 7.5. Table 19 indicates that C grade Haydite is superior to other mediums used. The cinders used in these tests were alkaline, and the sweet peas produced heavily in this medium. Production was low in silica gravel. Calcareous gravel, although desirable because of its pH range, is not as well aerated as cinders or Haydite and is less desirable for that reason. The B grade Haydite is recommended for commercial use.

TABLE 19.—Production of sweet peas in a 2 WP solution with various mediums.

Medium	Stems per foot of row
C Haydite	197
Silica gravel	83
Coarse cinders	190
Calcareous gravel	114

Boston Yellow Daisy

COMMERCIAL CULTURE.—Plants may be benched directly from the propagation bench or from 2½-inch pots. These plants grow exceptionally well in gravel with either a WP or 2 WP solution.

COMPARISON OF SOIL AND GRAVEL.—Differences in production between Boston yellow daisies grown with the WP solution in a V-bottom bench containing various mediums and those grown in commercial soil culture were marked (table 20). The B grade Haydite is recommended for commercial use.

TABLE 20.—Production of Boston yellow daisies in various mediums.

Medium	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil	52.1	9.6	2.1
Coarse cinders	61.8	13.9	2.3
Calcareous gravel	54.8	13.8	2.3
C Haydite	74.6	13.4	2.3

More flowers were produced on plants grown in nutrient solutions, although the differences in calcareous gravel were less, possibly because of the alkalinity of this medium C grade Haydite proved the best medium of those tested. Stem lengths were significantly greater in all mediums, compared with soil, and flower diameters were one-fourth of an inch larger in all mediums. The differences in the size of the plants are illustrated in figure 18.

Fig. 18.—Comparative growth of Boston yellow daisy in soil (left) and gravel (right).

Pansy

COMMERCIAL CULTURE.—This crop can be grown in the usual manner by benching plants that are well established in $2\frac{1}{2}$-inch pots with equal parts of FF Haydite and peat as a medium. Infrequent pumping after benching aids in preventing rot, which often develops on this soft-stemmed crop.

COMPARISON OF SOIL AND GRAVEL.—The production of Oregon Giant pansies in a flat-bottomed bench with a WP solution compared with normal soil culture is shown in table 21.

Although drainage conditions were poor, more flowers with longer stems were produced in gravel than in soil.

TABLE 21.—Production of Oregon Giant pansies in soil, cinders, and silica gravel.

Medium	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil	7.2	4.0	2.0
Cinders	8.9	5.5	2.4
Silica gravel	9.8	4.5	2.0

Feverfew

COMMERCIAL CULTURE.—Rooted cuttings direct from the propagation bench or well-established plants in 2½-inch pots may be used as benching stock. The plants grow satisfactorily on a WP solution, but the solution should be raised to a 2 WP level later to prevent the development of light-colored foliage and small flowers.

COMPARISON OF SOIL AND GRAVEL.—A test similar to that with Boston yellow daisy was made with feverfew. In addition, feverfew was planted in C grade Haydite with a ball of soil to determine the effect of this planting method on production.

TABLE 22.—Production of feverfew in various mediums.

Medium	Ounces of cut flowers per plant
Soil	11.8
Coarse cinders	12.6
Calcareous gravel	11.6
C Haydite	13.3
C Haydite, planted with a ball of soil	22.7

The differences in production were smaller than had been noted with other crops, and calcareous gravel was slightly inferior to soil. The greatest difference occurred where plants were placed in the bench with a ball of soil; the production of these plants was almost doubled.

Orchids

It has long been an accepted practice among orchid growers to grow epiphytic forms on an organic material known as osmunda fiber, the roots of the cinnamon fern and its allies. To this, only water is applied. In some instances, manure water or liquid fertilizer in various forms has been used with varying degrees of success. Most of these trials have been total failures.

Although volumes have been written on the culture of orchids, very little scientific investigation has been done in relation to nutrition, photosynthesis, or respiration.

The work of Knudson (7) on the nonsymbiotic culture of orchid seedlings on an agar medium to which inorganic salts and sugar were added paved the way for further studies on nutrition.

MEDIUMS.—Haydite and silica gravel have proved satisfactory potting material for orchids. Providing anchorage, support, excellent drainage, and aeration, these materials do not decay as does osmunda. A desirable moisture content is easily maintained, but fertilization must be practiced.

POTTING OR BENCHING.—Any size plant may be transferred from osmunda to gravel. Since ample aeration and drainage is a characteristic of gravel, one piece of crock over the drainage hole, when potting, is sufficient to prevent loss of the gravel. There is no need to fill half of the pot with broken crock before adding gravel except as a saving of the medium. Screening the gravel is unnecessary. Potting is reduced to a few short steps: (1) covering the drainage hole, (2) holding the plant in the correct position, (3) pouring in the gravel, (4) staking, and (5) tying. It is a simple matter to pot large numbers of plants quickly by this method. Benching the plants directly in gravel has not proved desirable, because root growth is so abundant that, when lifted, recovery of the extensive root system is often slow. Species with monopodial growth habit could remain undisturbed longer than sympodial branching species.

SEEDLINGS FROM THE FLASK.—As soon as roots begin to develop on seedlings in the flask, they may be transplanted into FF Haydite mixed with one-half chopped osmunda for better anchorage.

SEEDLINGS FROM COMMUNITY POTS.—Careful handling to avoid breaking roots should be practiced when tearing apart the mass of plants. Sufficient peat to cover the roots and serve as an anchor before many new roots develop is beneficial. There is no fear of overpotting in gravel since aeration and drainage are excellent. A mixture of 1/16 to ⅛ inch gravel with ¼ to ⅜ inch gravel is a good potting medium. Plants from community pots may be placed directly into 3-inch pots where they may remain several years.

SEEDLINGS FROM SMALL POTS.—The seedlings are removed from the thumb pot, the rotted osmunda is discarded, the plant is placed in position in a 3- or 4-inch pot, and the space around the osmunda is filled with Haydite. The B-grade Haydite is recommended and the presence of some finer particles aid in maintaining a more uniform moisture content. A very small osmunda ball serves as an anchor until the plant is firmly established with the development of new roots.

LARGER PLANTS.—The treatment of these plants is comparable to that given plants taken from small pots. On removal from the pot, the rotted osmunda is trimmed away almost entirely and the plant is held in position in a large pot. Gravel is poured around the ball. It is finished, staked and tied, and operation is complete.

WATERING.—More frequent applications of water are necessary than with osmunda-grown plants. Overwatering seldom occurs with coarse gravel, but fine gravel retains moisture for a longer period. Especially during cloudy, dark periods, fine gravel may be kept too wet. Plants potted with bare roots will require more frequent watering than those with a ball of osmunda. During high temperatures and bright days, frequent watering is necessary. During the summer, small pots should be watered every fourth or fifth day and large pots every week. With the advent of winter, the interval between watering periods should be extended to 10 days. The temperature and light will govern the interval between watering.

SUBIRRIGATION.—To subirrigate orchid plants, the same type of bench and other equipment is necessary as described earlier in this bulletin. A shallow layer of gravel placed on the bench bottom will provide a level place to set the pots. Gravel filled pots may be set into the bench and subirrigated. During the summer, weekly irrigation of mature plants is sufficient. As day lengths shorten and temperatures and light intensities fall, the interval between pumpings may be increased. Plants in gravel-filled pots may also be set on the bench or racks as are osmunda potted plants. Treatment is the same as that of plants in osmunda, but watering is necessarily more often.

Another method is that of subirrigating gravel-filled pots plunged to the rim in gravel. The increased amount of gravel decreases drying. During the summer, irrigate every tenth day and increase the period during the winter. Roots often grow into the surrounding medium so that shifting is a problem. The entire portion run on one subirrigation line should be planted with the same variety and potting methods should be the same. Similar plants and potting give a desired uniformity which is adaptable to gravel culture. Seasonal variations permit changes in the frequency of floodings. In all cases of subirrigation, the solution should be allowed to remain on the roots for at least six hours.

FERTILIZATION.—In their native habitat there usually is an accumulation of organic matter around orchid roots. Slow decomposition, plus settling of dust particles, provides a source of elements necessary for plant growth. Even though the amount is small, it is adequate for growth.

Decomposition of osmunda or other potting mediums may also supply small quantities of nutrients. Gravel, an inert material, neither decomposes nor has a supply of nutrient elements. The WP solution is used as a source of nutrients but it should be applied at one-half strength. A higher concentration usually shows no beneficial effects on growth and is a waste of fertilizer.

During the growing season, application of the ½ WP solution is beneficial about every second watering. During the summer, the ½ WP solution is applied every time the plants require water. As the plants go into dormancy, or when unfavorable growth conditions such as cool, cloudy or dark days occur, the fertilizing program is reduced. Upon the resumption of growth or good growing conditions, the ½ WP solution should be applied more often.

SUPPORT.—Because of the loose character of gravel, orchid plants are not as well anchored in gravel culture as they are osmunda. Figure 19 shows a pot clip made of No. 9 wire which is useful for support and tying.

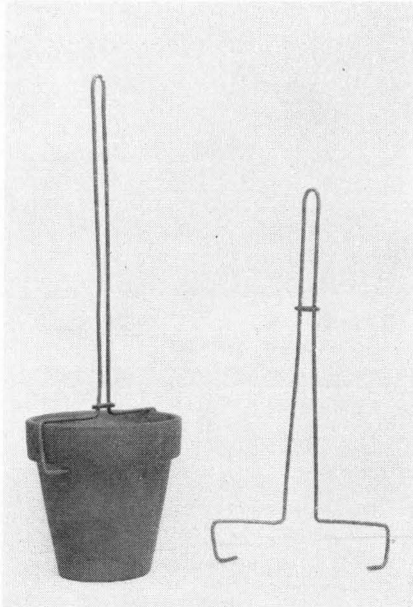

Fig. 19.—Orchid pot clip.

MISCELLANEOUS CROPS

EUPHORBIA FULGENS.—Plants out of 2½-inch pots with equal parts of FF Haydite and peat as a medium, do exceptionally well in gravel culture under conditions of perfect drainage. When the plants are established, a 2 WP solution is best.

CALLA LILIES.—Satisfactory growth and good production result when calla lilies are grown in gravel. It is important that the tubers be free of root rot, since this disease is transmitted readily through the solution from plant to plant. The 2 WP solution is most suitable.

BULBOUS AND CORMOUS PLANTS.—Gladiolus, bulbous iris, narcissus, hyacinths, freesia, ornithogalum, tulips, and many species of the genus Lilium were grown satisfactorily in the WP solution. (figs. 20 and 21.)

Fig. 20.—Wedgewood iris in C grade Haydite.

Fig. 21.—King Alfred narcissus in C grade Haydite.

TUBEROUS-ROOTED BEGONIAS.—Grown in gravel in a 2 WP solution, these plants produce large flowers in profusion on long stems.

GERANIUMS.—When grown for stock plants in gravel, geraniums produce large quantities of cuttings of exceptional quality.

Other plants that have been grown successfully in gravel culture since 1937 include calendula, bouvardia, buddleia, gerbera, marigold, candytuft, dahlia, annual chrysanthemums, salpiglossis, centaurea, and didiscus

COMPARATIVE COSTS OF SOIL AND GRAVEL CULTURE

A drawback in commercial practice of gravel culture is the apparent high cost of installation. The cost is not high, however, if the initial installation costs are prorated over a period of years. An examination of a specific case will illustrate the point.

The costs of construction of an overhead watered soil bench and one equipped for gravel culture based on costs of materials in 1948 for a house 50 x 200 ft. containing 8 benches is shown below:

Items	Gravel Culture	Overhead watered, soil
Benches	$3200	$3200
Equipment	700	.....
Haydite or soil and manure	600	600
Total	$4500	$3900

Initial costs are higher for gravel culture, but the savings effected per year are shown below:

Items	Gravel Culture	Overhead watered, soil
Fertilizer, per year	$ 70	$ 75
Testing, per year	50	5
Depreciation and operation of equipment, per year	100	.....
Mulching	.....	200
Watering	.....	400
	$ 220	$ 680

It is apparent that the costs of maintenance are lower in gravel culture, and greater production of higher quality flowers per square foot may be expected in gravel.

SUMMARY

Benches constructed for gravel culture should be perfectly waterproofed and built to make complete drainage of the solutions possible.

Tanks should be waterproofed and should be large enough to contain at least 40 percent of the volume of the benches they serve.

Black pipe should be used in preference to galvanized to avoid toxicity from zinc.

Four-inch half-tile makes the most satisfactory trough for the bottom of the bench.

Sump pumps are easier to install than centrifugal pumps and should be of sufficient capacity to provide rapid flow and quick return.

Haydite, trap rock, silica gravel, cinders, and calcareous gravel make suitable mediums for plants, although some difficulties may be experienced with cinders and calcareous gravel.

Of all solutions tried, the WP formula was found to be the most satisfactory for most crops.

Solutions should be changed about once in 2 months, although with care, longer intervals may be acceptable.

Colorimetric microchemical tests should be made once a week for pH and phosphorus and once in 2 weeks for nitrates and potassium.

The maintenance of a pH of 6 to 6.5 will be found satisfactory for most crops.

The number of times the solution should be pumped per day varies with the crop and the season. Four times a day is ample in the summer, and once a day in the winter. Some crops, like carnations, may need even less frequent applications of solutions.

To avoid the formation of algae on the surface of the medium, the solutions should be pumped only to within 1 inch of the surface.

Dormant-budded roses are best for gravel culture and should preferably be planted in January or February. The 2 WP solution has proved very satisfactory for roses, although additions of potassium to it during winter resulted in greater production. The use of ammonium nitrogen at a pH of 5 or below causes yellowing, defoliation, and check of axillary bud development on roses. Gravel-grown roses can be dried off somewhat similarly to those grown in soil. Frequent syringing of roses is safer in gravel than in soil, since there is no danger of creating too moist a medium.

The base of galvanized stakes should be covered with asphalt before use, to avoid toxicity from zinc. Because of optimum conditions in gravel culture, greater production and better quality of roses result.

A number of other important cut flower crops can be grown profitably in gravel culture. These include chrysanthemums, carnations, gardenias, asters, snapdragons, orchids, lilies, stocks, sweet peas, Boston yellow daisies, pansies, feverfew, and others.

Plants grown in pots prior to benching should be placed in a medium consisting of equal parts of FF Haydite and peat rather than soil because of the dangers of stem rot when benching with a soil ball. Fertilization with a WP solution weekly is necessary in the Haydite and peat. Washing the soil ball from the plant roots checks the growth of the plants, probably because of injury to the roots.

Chrysanthemums should be benched in gravel culture as rooted cuttings directly from the propagation bench. A WP solution should be used in the early stages, and when the plants are established, the solution should be raised to a 2 WP nutrient level. More frequent pumpings are necessary with the stronger nutrient solution.

With gardenias the presence of a ball of peat is not injurious when the plants are benched. The same manipulation of solution is made on gardenias as with chrysanthemums.

Carnations may be benched as rooted cuttings or as well-branched plants grown in nurse beds in gravel culture. Solutions are manipulated in accordance with the season. A WP solution is used in summer and winter, and a 2 WP solution for fall and spring. Potassium additions during the winter months strengthen the stems. Carnations require less frequent applications of solutions per day than many other crops.

Orchids grown in gravel culture, particularly when pumped automatically, produce plants and flowers fully as satisfactory as those in osmunda. However, the enormous savings in labor resulting from potting in gravel compared to osmunda makes gravel culture extremely desirable.

Lilies, snapdragons, asters, and other crops respond well to gravel culture.

The initial costs of equipment are higher for gravel culture than for soil. If its cost is prorated over a period of years, gravel culture is not any more expensive than soil culture, and because of labor savings and greater perfection of growth, it is actually more profitable.

APPENDIX

TABLE I.—Composition of the various nutrient solutions.

Nutrient solution formulas	Grams per 1,000 gal. of water	Per 1,000 gal. of water lb.	oz.	Millimolar concentration
Ohio WP				
Potassium nitrate, 13-0-44, KNO_3	2,630	5	13	6.9
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	439	0	15.5	.9
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	2,043	4	8	2.2
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	1,090	2	6.5	1.4
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	4.856	10	12	7.5
Ohio W				
Potassium nitrate, 13-0-44, KNO_3	2,630	5	13	6.9
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	2.043	4	8	2.2
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	1,090	2	6.5	1.1
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	4,856	10	12	7.5
Purdue 2D				
Magnesium sulfate, $MgSO_4$ (anhydrous)	246	0	9	.5
Treble superphosphate, 0-48-0, $Ca(H_2PO_4)_2 \cdot H_2O$	586	1	5	.6
Potassium nitrate, 13-0-44, KNO_3	4,158	9	3	10.9
Calcium sulfate (gypsum), $CaSO_4 \cdot 2H_2O$	2,873	6	5.5	4.4
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	529	1	3	1.1
Purdue 2E				
Magnesium sulfate, $MgSO_4$ (anhydrous)	246	0	9	.5
Treble superphosphate, 0-48-0, $Ca(H_2PO_4)_2 \cdot H_2O$	586	1	5	.6
Potassium nitrate, 13-0-44, KNO_3	2,495	5	8	6.5
Calcium nitrate, 15.5-0-0, $Ca(NO_3)_2 4H_2O$	2,722	6	0	3.0
Ammonium nitrate, 35-0-0, NH_4NO_3	605	1	5.5	2.0
New Jersey (carnation)				
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	600	1	5	1.2
Monobasic potassium phosphate, KH_2PO_4	2,280	5	0.5	4.4
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	2,320	5	2	2.5
Calcium nitrate, 15-0-0, $Ca(NO_3)_2 \cdot 4H_2O$	7,000	15	7	7.8
Hoagland's TC				
Monoammonium phosphate, $NH_4H_2PO_4$	434.7	0	15.3	1.0
Potassium nitrate, KNO_3	2,293.2	5	1.0	6.1
Calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$	3,568.5	7	13.5	4.0
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	1,863.5	4	1.8	2.0

TABLE II.—Parts per million composition of some nutrient solution formulas
Based on complete solubility of all salts.

Formula	Nitrate	Ammonium	Ammonium to nitrate	Total nitrogen as nitrate	Phosphorus	Phosphate	Potassium	Calcium	Magnesium
Ohio WP	400	28	100	500	65	200	250	310	51
Ohio W	400	....	......	400	65	200	250	310	51
Purdue 2D	627	36	124	751	31	96	395	200	120
Purdue 2E	835	35	120	955	31	96	237	200	120
New Jersey (carnation)	875	40	140	1,015	130	408	170	283	58
Hoagland's TC	868	18	62	930	31	95	235	160	49

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